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MECHANICAL REFRIGERATION

BEING A PRACTICAL INTRODUCTION TO THE STUDY OF COLD STORAGE, ICE-MAKING AND OTHER PURPOSES TO WHICH REFRIGERATION IS BEING APPLIED

BY

HAL WILLIAMS

M.I.MECH.E., M.I.E.E., M.I.STRUCT.E.

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PREFACE

I AM informed that the second reprint of the 1933 edition of MECHANICAL REFRIGERATION is exhausted.

Publishers are sometimes unfeeling persons, and to descend —in the middle of a total war—upon an overworked Engineer who, incidentally, has been bombed out of office and home, for a new edition of a heavy technical book is an act which even they recognize as unreasonable. All the same, "time marches on," as the news films say, and in recent years many changes have taken place. Some of the companies whose machines were described in Chapter V have ceased to exist or have been absorbed by other companies, while models have changed

In the application of refrigeration to industry changes have taken place and progress has been continuous.

While it cannot be claimed that this is a complete revision, care has been taken, within the limits of reasonable production costs, to bring the work up to date. Once again my thanks are due to Mr. A. G. Clausen for his invaluable help.

HAL WILLIAMS

43 BEDFORD SQUARE
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1941

PREFACE
TO THE FOURTH EDITION

ONCE again the publishers have descended upon me with an urgent demand for a further—the fourth—edition of MECHANICAL REFRIGERATION.

Since the last edition was published the design of refrigerating machines has altered, and many new illustrations have been included in Chapter V to mark the progress made in the science. Great progress also has to be recorded in the manufacture and use of Solid CO_2 (Dry Ice): in refrigerated trucks and vehicles for the transport of produce requiring a low temperature; in the quick freezing of fish, meat, and other articles, and in the design of abattoirs as applied to this country.

Mechanical refrigeration is becoming more and more the handmaiden of industry, and there are now few manufacturing concerns which can dispense with her salutary, if chilly, embrace.

For the rest, MECHANICAL REFRIGERATION is still written for the information of the owner, user, and student, rather than for the technician. Some of the matter in the book has appeared in other places, and, as before, the thanks of the author are due to Mr. A. G. Clausen and all those who, as mentioned in previous editions, have so willingly and so kindly assisted him in the revision.

HAL WILLIAMS

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MECHANICAL REFRIGERATION

INTRODUCTION

THE GENERAL PRINCIPLES

THOSE people who have been sufficiently interested to give any thought to the subject are familiar with the phenomenon of the conversion of heat into work, as exemplified in the steam-engine and in other heat-engines. The operation of the refrigerating machine may best be described as the direct opposite of that process, namely, the conversion of work into heat in such a way—paradoxical as it may seem—as to result in the production of cold. The steam engine had been at work for many years before the laws governing its action were guessed at or understood, and in the same way most arts and sciences, as practised to-day, have been no invention, but have originated in the dim past, have been the direct result of the common need of things, and have developed by the exercise of ordinary common sense and instinct, by rule of thumb, and by trial and error. The science of refrigeration, on the other hand, shares with that of electricity the distinction of being the direct outcome of scientific research. The whole development of each has been guided in a remarkable manner by theory derived from the study of scientific facts; and, as in 1831 the study of the laws of magnetism enabled Faraday to discover the possibility of turning mechanical into electrical energy by means of electro-magnetic induction, so a study of the laws of thermo-dynamics enabled men like Gorrie, Harrison, Perkins, Coleman, Linde, and Windhausen, to mention only a few, to discover, invent, and work apparatus for the removal of heat, or, in other words, the production of cold.

The Basic Law of Refrigeration. One of the most remarkable, and to the uninitiated one of the most puzzling, things about refrigeration is the fact that in order to produce cold heat must be expended. The explanation is really very simple. The first law of thermodynamics tells us that both heat and work, or mechanical energy, are mutually convertible ; and the second—and this is the important point—that heat cannot be raised from a lower to a higher level of temperature (that is to say, cannot pass from a cold body to a hot body) without the expenditure of some external energy. Owing to a confusion of the meaning of the two terms " heat " and " cold " and of the origin of heat, cold is often, in error, spoken of as if it were some substance complete in itself. Cold is merely an absence of heat, and people should not speak of " allowing cold to escape " when they mean " allowing heat to enter." The production of a state of cold consists entirely in depriving a body of its heat. It is consequently necessary, in order to conform with the second law of thermo-dynamics, to expend external energy and it will be found that the great bulk of modern refrigerating machines consists of a heat pump, driven by a steam engine, an oil engine, a gas engine, or an electric motor. The remainder consists of machines which employ the direct action of heat, and do not make use of mechanical work at all.

As water is always trying to find its own level, so heat is always endeavouring to balance itself, and when once a substance is cooled or refrigerated it will tend to absorb heat from some warmer substance until its temperature is again that of its surroundings. The term refrigeration suggests that the reduction in temperature of a body should be maintained as well as originated, and to effect this it is necessary, by means of some medium which is capable of absorbing heat, to keep on pumping the heat out of the body to be kept cool as fast as it flows in. Pumping heat is perhaps an unusual expression, but it is the principle underlying refrigeration. The heat absorbed from the cold body is raised by a compressor or pump to a high level of temperature—that is to say, to a temperature higher than the normal temperature of some substance that will, while in its natural condition, receive heat from it. In practice this substance is always water, which is circulated around pipes or over coils containing the heated medium. By this means an exchange of temperature takes place, the heat tends to equalize itself, and the water becomes warmed while the medium becomes cooled.

Theoretical Efficiency. In a heat engine, heat at a high temperature is taken from the coal or other source, is put into the engine, and, after doing a certain amount of work which appears as mechanical energy, is exhausted or rejected at a low temperature. In a steam engine, for instance, high pressure or hot steam is admitted behind the piston and forces it along the cylinder ; as the piston moves the steam behind it expands, and the temperature drops. The higher the high temperature (T_1) at which heat is taken in, and the lower the low temperature (T_2) at which it is exhausted, the more efficient the engine. Expressed as an equation, the efficiency E of the heat-engine is

$$E = \frac{T_1 - T_2}{T_1}$$

while the efficiency E_1 of the refrigerating machine is exactly opposite, or

$$E_1 = \frac{T_2}{T_1 - T_2}$$

and the smaller the difference between T_1, the high temperature at which the heat is rejected, and T_2, the low temperature at which it is taken in, or, in other words, the smaller the " head " against which the heat has to be pumped in being raised from the lower to the higher level of temperature, the more efficient the refrigerating machine will be.

As a consequence of this, in a refrigerating machine driven by a steam-engine there is, in order to get the most perfect combination possible, at the one end a steam cylinder with the difference between T_1 and T_2 as *big* as possible, and at the other a compressor with the difference between them as *small* as possible.

Classification of Refrigerating Machines. Refrigerating machines may be roughly divided into two classes: (1) Machines which use air and are practically obsolete, and (2) those which use some chemical agent having a low boiling-point, and which produce their refrigerating effect by alternately condensing and vaporizing this agent. Of this latter class there are two sub-divisions: (*a*) Those which use heat direct to produce cold, or the absorption machines; and (*b*) those which produce cold by the expenditure of mechanical energy in working a heat pump, or the compression machines.

Choice of the Refrigerating Agent. Apart from the conditions under which the refrigerating machine is going to be used, i.e. whether in an hotel, at sea, etc., the choice of a refrigerating agent is governed by its boiling-point at ordinary pressures; the latent heat of vaporization per pound; the number of cubic feet of vapour or gas that must be compressed to produce a certain refrigerating effect, or, in other words, the size of the compressor necessary; the pressure required to produce liquefaction of the gas at certain temperatures, and the specific heat of the liquid.

The properties of the three chief refrigerating agents are set out in round figures in the following table*—

	Pressure in lb. per square inch at 0° F.	Heat of vaporization per lb. at 0° F.	Volume in cubic feet per lb. at 0° F.	Specific heat of liquid.	Heat of vaporization per cubic foot.	Relative volume of compressor for equal refrigeration.	Loss due to cooling liquid. p.c.
Sulphur dioxide . .	10	171·2	7·35	·41	23·3	61·70	0·24
Carbon dioxide . .	310	123·2	0·277	1·00	447	3·24	0·81
Ammonia . . .	30	555·5	9·10	1·02	61·7	23·3	0·18

All these substances have a boiling point much below the normal. Ammonia, for instance, in the above table, at atmospheric pressure becomes liquid at a temperature of - 30° F. Before it can be turned from a gas into a liquid, it has to be robbed of its latent heat, and it naturally follows that if its latent heat is restored to it, it will begin to boil and again become a gas. In boiling it will absorb heat from any substance that may be near it, and on being compressed the gas will, in its turn, deliver up the heat so absorbed, to the cooling water trickling over the condenser, and again become a liquid. The class of machine using a volatile liquid is separated into two divisions: (*a*) the absorption machine, and (*b*) the compression machine.

---

* J. E. Siebel, *Compend of Mechanical Refrigeration.*

The Absorption Machine. The absorption machine depends for its working on two substances that have an affinity for each other. When the machine is not at work these substances are united, but their nature is such that on the application of heat their state is changed, and they can be separated from each other. The principal substances used in absorption machines are either sulphuric acid and water or ammonia and water. It is well known that ammonia and water have a great liking for each other, and, if allowed to, will readily unite; but if heat from, say, a steam-coil, is applied to them when in their united condition, they will separate, and the ammonia will be driven off as a vapour under pressure. The vessel containing the ammonia and water and the steam-coil is called the generator, and as the ammonia vapour driven off is not entirely free from water, it has, in order to render it free from water or anhydrous, to be passed through an upright vessel called an analyser, containing a series of iron trays which catch any watery vapour that may have been carried off and return it to the generator, after condensation, as water. The ammonia vapour, now very nearly free from water, passes to the rectifier, where the remaining watery vapour is condensed and separated, and then to the condenser, where it is liquefied. From the condenser it passes through a regulating valve to the refrigerator, where the pressure is relieved and it re-evaporates. In doing so it absorbs heat from the brine, water, or other substance which circulates round it, and which is to be cooled. The ammonia gas which has evaporated is reabsorbed by the water from which it was driven off and is returned to the generator by a small pump. This small pump is the only moving part of an absorption machine, and requires very little power to work it. In some absorption machines even the pump is dispensed with and there are no moving parts. The absorption machine is more economical than the cold-air machine, but not so economical as the compression machine. Professor Ewing has found that the absorption machine is from two and a half to three and a half times as efficient as the cold-air machine, and that the compression machine is from five to six times as efficient as the cold-air machine, and from two and a half to three times as efficient as the absorption machine.

The Compression Machine. Fig. 1 shows diagrammatically the general arrangement of a compression refrigerating machine, using ammonia or some other volatile liquid. Assuming that the machine is working with ammonia, the gas from the refrigerating or expansion coils *A* is drawn into the compressor *B* through the pipe *C* and the valve *D*; on the return stroke of the compressor piston *E*, the valve *D* is closed and the gas is compressed and driven through the valve *F* into the pipe *G* leading to the condenser *H*. The ammonia gas in the suction pipe *C* is at a pressure of about 27 lb. on the square inch, and at a temperature of 14° F. It contains the heat which has been absorbed from the atmosphere in the cold chamber, and which was necessary to turn the ammonia from a liquid to a gas. By being compressed this gas is decreased in bulk, and the heat contained in it is, so to speak, concentrated, so that the gas in the pipe *G* is at a temperature much above that of ordinary cold water. The condenser *H* has cold water trickling over it: this water is at a temperature of about 60° F., and absorbs the heat (representing the latent and specific heat of the ammonia and also the heat due to the energy of the prime mover) from the gas inside the coils and carries it away. The gas, robbed of its heat, can no longer remain a gas, and becomes liquid in the same way that steam, if cooled, will condense. Though a liquid, it is obvious that the ammonia will be ready to start boiling, and again turn to a gas, as soon as the pressure upon it is relieved. This is done by passing it through a minute opening in the regulating valve *K*. When the ammonia has passed through this valve it starts boiling and drops many degrees in temperature. Before it can boil, however, it must absorb heat, and as 1 lb. of ammonia requires, at atmospheric pressure, 589·3 heat units before it can turn into a gas, these heat units have to be abstracted from the substance surrounding the expansion coils *A*, which, as a result, rapidly become covered with snow.

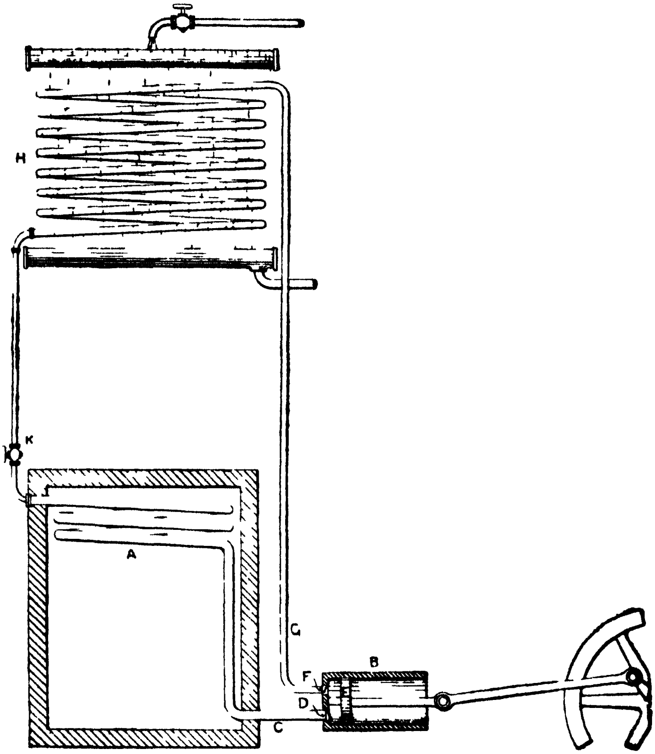


Fig. 1

It will be seen that the cycle of operations consists of three parts—

1. Compression or reduction in volume, and increase in temperature.
2. Condensing or giving up heat, and liquefying.
3. Evaporating (boiling) or absorbing heat, and so gasifying.

In practice the pressure in the expansion coils is kept at from 1½ to 30 lb. (corresponding to a temperature of from -22° to 17°) by the suction of the compressor, which is continually drawing off the gas as it is formed; but on account of the desirability of keeping T_1 and T_2 close together, the pressure, and so the temperature, is kept as high as possible consistent with the work the machine is doing. It is apparent that if the liquid ammonia is constantly fed into the expansion coils *A* through the valve *K*, and the gas drawn away by the compressors, a great amount of heat will be absorbed by the boiling ammonia in the coils, and that if these coils are placed in an insulated chamber, as shown in the diagram, that chamber will be rapidly reduced in temperature or refrigerated. The same remark, of course, applies to an ice-tank, in which the expansion coils are surrounded by brine, which is reduced in temperature, and so freezes the water contained in cans suspended in it.

The cycle above given applies to all of the vapour compression refrigerating machines; the details vary with different makers, and, of course, the size and strength of the various parts vary with the peculiarities of the particular refrigerating agent used. The relative volumes of the compressors are shown in the table previously given, and it is the size of the compressor necessary to produce a certain refrigerating effect that has so largely discounted sulphurous acid as a refrigerating agent. Thus it is that the ammonia and carbonic acid compression machines now practically hold the field.

CHAPTER I

THE LAWS OF HEAT, FLUIDS, LIQUIDS, GASES, AND VAPOURS

THE refrigerating machine is essentially a heat engine reversed, and a proper knowledge of the physical laws that regulate the behaviour, under various conditions, of the gases and vapours which are employed in it is necessary before its action can be properly understood. These are now given, very simply.

Heat

All substances are capable of existing in one of three forms, and can be a solid, a liquid, or a gas, the change from one form to another being brought about either by the addition to, or withdrawal from, the substance of heat which is the source of all energy. All material substances, in whichever of these three forms they exist, consist of an infinite number of separate particles or molecules. Heat is a form of motion of these particles, and though the energy of this motion may be transformed and transferred, it can never be destroyed. When a body is in motion, it is said to have kinetic energy, and heat is represented by the kinetic energy or motion of the molecules of a body or substance ; the greater the heat, the greater the motion, and vice versa. When, however, a body, by the transference of its heat to some other body, has been reduced to the temperature of absolute zero (which will be referred to later on), heat is entirely absent, and the particles or molecules of the body are absolutely at rest and without internal energy of any sort.

Temperature. The degree of heat of a body, or its thermal state, depends on the motion of its molecules, and is known as its temperature. This temperature is measured by the thermometer, the scales of which have been arbitrarily fixed—hot and cold being only relative terms—and depends upon the amount of energy the particles of the body possess.

Transference of Heat. Heat can be conveyed from one body to another in three ways—by radiation, conduction, or convection. The phenomena connected with the transference of heat are most complicated, and all these three processes may take place singly or at the same time.

Radiation of Heat. Radiant heat is heat which can pass from one body to another through what is called the ether—that is to say, it is transmitted, like the heat of the sun, without the assistance of any material medium. It is always a transference of vibratory motion from a hot body to a cold, and the transference will continue until the source of heat is cut off or the temperatures are equalized. The passage of this radiant heat has no effect upon the temperature of the medium through which it passes, this remaining unaltered. The heat is also capable of being reflected or focused, and in this respect is governed by exactly the same laws as light. It is, in fact, only when it becomes absorbed by the body upon which it falls that it is, strictly speaking, called heat ; in the ether it is radiant energy.

Conduction of Heat. Heat is conducted when it is transferred from one body, or part of a body, to another by the means of some material medium or by actual contact. All substances have to a greater or lesser extent this power of allowing heat to flow through them. This property is called conductivity. A substance that offers little obstruction to the flow of heat is called a good conductor, while a substance which offers great resistance is called a bad conductor or an insulator.

Convection of Heat. The convection, or carrying of heat, takes place, as its name implies, when heat is bodily moved from one place to another in a fluid mass by means of the actual motion of that mass itself, such as, for instance, the carrying of heat by steam, heated air, or by hot water circulating in pipes. Heat can also be absorbed and reflected in the same way that light is absorbed by black or reflected by a bright surface. Generally speaking, light and heat follow the same law in this matter, and as a good reflector of light is a bad absorber, so a good reflector of heat is a bad absorber or radiator. An exception to this rule, which is of importance in cold storage work, is white lead, which, owing to its metallic nature, absorbs and reflects heat in an equal degree.

Absolute Zero. At the temperature of absolute zero there is an entire absence of heat, and, as previously explained, the molecules of a body having lost all motion are at rest. The temperature at which this occurs is believed to be – 460° F. This figure has been determined because the expansion of a perfect gas under constant pressure is at freezing-point 1/492 of its volume for each degree change in its volume, and it follows, as a matter of course, that if it were cooled down to a temperature of 460° (492 – 32) below zero Fahrenheit, its volume would become zero, and all motion would cease. The late Professor Kamerlingh Onnes reached within four-fifths of a degree of absolute zero.

Expansion of Heat. If molecular heat motion may be regarded as a form of vibratory motion of the particles of a substance, such motion of the individual particles would tend to separate them, and, obviously, if it were intensified, or, in other words, the temperature were raised, each particle would naturally require more space in which to move, and the whole warm mass would occupy a greater space than it did when cold. Accordingly, most bodies expand when heated and contract when cooled, the exceptions being water, and many metals near to but above their melting point.

Latent Heat. All substances can exist in one of three forms—a solid, a liquid, or a gas—and they may be changed from the one to the other by the agency of heat. When, however, this change is taking place, and a body is altering its molecular constitution, in passing from a solid to a liquid, or a liquid to a vapour, a certain amount of heat is required to increase the energy of the molecules, overcome the force of cohesion, and thus produce the change. In changing back from a liquid to a solid this heat is given up. In either case the heat does not appear sensibly—that is to say, it cannot be felt or measured by the thermometer—and it is, therefore, known as latent heat. At the same time this latent heat may be abstracted from the substances themselves, thus producing a fall in temperature, and this is what happens in the case of frigorific mixtures.

Heat Capacity. The heat required to be absorbed by various substances before their temperature can be raised one degree varies with the substance, and the amount of heat thus required by any given substance is called its heat capacity.

Specific Heat. The capacity for heat possessed by one pound of water—i.e. the heat required to raise its temperature one degree—is always regarded as unity, and the capacity for heat possessed by any other substance in comparison to water is called its specific heat.

Sources of Heat. There are several immediate sources of heat, the principal being solar radiation, friction, percussion, mechanical stress, terrestrial heat, electric action, and chemical combination (of which combustion is a special case). It is apparent that these sources have originally derived their supply from solar radiation, as, for instance, in the formation of the coal measures.

Chemical Combination. Heat formed by chemical combination may be best described as the heat that results when the constituent parts of one or more elementary bodies unite together chemically to form a body or substance entirely different from the original bodies. This definition is further explained by the fact that the newly formed substance possesses less energy than did the original component parts before they united. The difference of energy before and after the combination appears in the form of heat or electricity. When chemical compounds are again decomposed into their elementary parts heat is absorbed, and the energy of the elementary parts is increased to its former intensity.

Combustion. Combustion, the principal source of heat, is a chemical combination of carbon and oxygen (the carbon of the coal or coke with the oxygen of the air). This combination will only take place at certain temperatures, and before it can be started it is necessary to raise the temperature of the two bodies to the required point, which varies with different substances. The lower the temperature at which a body will begin to combine with the oxygen, and the more readily it will do so, the more inflammable it is said to be. The principal fuels are, of course, coal, coke, and fuel oil.

Unit of Heat. Heat can be measured, and the unit of heat used in English-speaking countries is the British thermal unit (usually written B.T.U.). This is actually the amount of heat necessary to raise the temperature of 1 lb. of pure water 1° F. from a temperature of 39·1, which is the point of maximum density of water. For all practical purposes, however, it may be, and is, taken as being the amount of heat necessary to raise 1 lb. of water 1° F., irrespective of temperature. The mechanical equivalent is 778 foot-pounds. The metric heat unit is the great calorie. It is the amount of heat required to raise 1 kilo. of water through 1° C. The equivalent is B.T.U. × 0·252 = great calorie. Great calories × 3·968 = B.T.U.

The calorie is one-thousandth part of the great calorie.

Fluids

A fluid is a substance which allows its molecules to be moved about to an indefinite degree by the exertion of the slightest force, and the difference between a fluid and a solid is that while a solid has rigidity, a fluid has none. Fluids are of two kinds—gases and liquids. This property of free movement of the particles in relation to each other is known as fluidity, and is possessed by gases to an even greater degree than by liquids. A fluid has the property of transmitting pressure exerted upon any part of it equally in all directions, and force transmitted through a fluid will act with equal pressure on all equal surfaces in a direction at right angles to those surfaces, as in a hydraulic press. It follows, therefore, that as pressure in a liquid is distributed in all directions, any substance floating upon water, and so creating a pressure upon it, will have a return pressure exercised upon itself, and will itself be borne up. This is known as buoyancy, and it is on account of this phenomenon that a substance weighed in water loses a portion of its weight equal to the weight of water it displaces.

Specific Gravity. By this means the specific gravity of a body is ascertained by comparing its weight in air to its weight when immersed in water– that is to say, its specific gravity is the ratio of its density to that of water. For solids the standard is pure distilled water at 60° F., weighing 1,000 oz., or 62½ lb. per cu. ft., while for gases it is atmospheric air at the same temperature and 30 in. barometric pressure, weighing 31 grains per 100 cu. in., or ·07 lb. per cu. ft. To ascertain the specific gravity of a solid, its weight in air is divided by the weight lost when weighed in water.

Gases

A permanent gas is an elastic fluid that cannot be liquefied, and it is exceedingly doubtful whether such a thing exists. Ordinary gases are those which will not liquefy at ordinary temperatures and pressures. All gases have weight—some, such as carbonic acid, being much heavier than air ; and others, such as hydrogen, being much lighter.

Compression and Expansion of Gases. If a gas is confined in a closed vessel and heat is applied, the energy of its molecules will be increased, the molecules will tend to separate, and the pressure will rise. If, however, heat is applied to gas in an unconfined state, it will expand freely and the pressure will remain constant, the energy which its molecules have derived from the heat being partly used in making room for the gas and giving it freedom to expand. The specific heat in the latter case is always greater than in the former.

Resisted Expansion of Gases. When a compressed gas is expanded while doing work, i.e. behind a piston, a certain quantity of the heat it contained—the exact proportion depending upon the amount of work it is allowed to do—will disappear as work, and the temperature will fall. It is this property which makes the cold-air machine possible.

Free Expansion of Gases. When, however, the pressure resisting the expansion of a gas is small, the gas is said to expand freely and does not perceptibly change its temperature. It has doubtless been noticed that when a refrigerating plant has been tested with air pressure, and the air is allowed to escape and expand from a pressure of, say, 300 lb. per sq. in. to that of the atmosphere, there is no perceptible fall in its temperature ; while if the same air was expanded while doing work in a cold-air machine or in a pneumatic drill or crane, its temperature would be many degrees below zero.

Mixtures of Gases. Two or more gases, if brought together, will thoroughly mix if sufficient time be given them. The rate of mixing depends upon the weight of the respective gases, and is inversely as the square root of their densities—that is to say, a heavy gas like CO_2 will take longer to mix with air than a lighter gas. This rule is equally true and holds good for a mixture of any number of gases.

Pressure of Gases. The pressure exerted upon the interior walls of a vessel or cylinder containing a mixture of gases under pressure is equal to the sum of the pressures which would be exerted if each of the gases occupied the same vessel alone. This is known as Dalton's law.

Volume and Pressure of Gases. If a gas is heated while its volume remains constant, its pressure will increase proportionally to the absolute temperature; while if it is heated while its pressure remains constant, its volume increases according to the same law—that is, for a rise of temperature of 1° F. its volume increases by a constant fraction (1/492) of its volume at 32° F.

Unit of Pressure. Pressure is measured in terms of the pressure of the atmosphere, which is taken as being equivalent to a pressure at sea-level of 14·7 lb. per sq. in. If this pressure of the atmosphere is removed by a vacuum pump and a vacuum formed, the vessel containing the vacuum is at once subjected to a pressure exerted upon it by the outside air in trying to flow in to destroy the vacuum. This property is made use of in suction pumps; the air in the suction pipe being removed by the action of the pump plunger, the water is forced up the suction pipe by the pressure of the air outside, and, as a pressure of 14·7 lb. on the sq. in. will support a column of water 34 ft. high, the water, theoretically, will rise to this level in the suction pipe. In actual practice, however, a height or suction head of from 20 to 25 ft. is the maximum obtainable, as, owing to the more or less imperfect valves of the water pump, a better vacuum can seldom be had.

Liquefaction of Gases. All gases will become liquid, provided a sufficient pressure is applied and the temperature is sufficiently lowered. When gases or vapours are compressed, the energy or work of compression appears in the form of heat, and has to be removed before liquefaction will take place. In a compression refrigerating machine the heat removed by the condensing water is made up of the sum of the heat equivalent of the work done in compressing the gas and the heat that has been conveyed from the cold chamber or ice tank by the refrigerating agent.

Critical Temperature and Pressure. There is, however, a point called the critical temperature above which no amount of pressure will cause liquefaction. In the same way the pressure necessary to liquefy the gas at or near its critical temperature is known as the critical pressure. This latter term, however, is not so commonly heard as the former.

Isothermal and Adiabatic Expansion and Compression. When a gas is expanded or compressed while its temperature remains constant, heat being added or taken away, it is said to be expanded or compressed isothermally ; but when, owing to no heat being taken away or added, the expansion or compression is accompanied by a change of temperature—that is to say, the gas gets hotter or colder—the change is said to be adiabatic.

Absorption of Gases. All liquids, some more than others, will, if left to themselves, take a certain amount of gas into chemical combination with themselves. During this absorption heat is given off, and if the gas has afterwards to be separated from the liquid, an equivalent amount of heat to that given off has to be added from an external source. This is the principle of the ammonia-absorption machine, the ammonia and water being allowed to combine, and then the ammonia being driven off by the application of heat.

Vapours

A vapour is merely a gas in a particular state, and is not a separate substance. When gases are lowered in temperature to their point of liquefaction, condensation begins to take place and they become charged with minute particles of liquid

—in fact, become moist; in this state they are often called vapours. For instance, ordinary high and low pressure steam is a vapour, while superheated steam is a gas. The term vapour is also applied to a gas below its critical point; thus, in this sense carbonic acid gas is a vapour at ordinary temperatures, while oxygen is not.

Saturated Vapours. When the vapour is on the point of liquefying, it is said to be in a saturated state, and is then at its point of maximum density. Any vapour can, like steam, be superheated. It then becomes a gas, with all the peculiarities of a gas. All liquids will, if exposed to the atmosphere, absorb heat from it and evaporate, part of the liquid becoming a vapour. In a closed vessel the evaporation will continue until the pressure in the vessel, due to the formation of the vapour, is equal to the maximum density of the vapour for the particular temperature at which evaporation is taking place. This evaporation only takes place from the surface of the liquid.

Boiling. When the temperature of a liquid becomes sufficiently high, vaporization will become rapid and take place from all points of the liquid, and what we know as boiling will occur. Bubbles of vapour will rise rapidly to the surface and there expand. The boiling point of the various liquids varies, but boiling or ebullition will take place in any given liquid at a constant temperature for a constant pressure. If the vessel is a closed one, and the pressure is increased by the rapid formation of vapour, the temperature at which boiling will take place will rise, and as the pressure rises, more and more heat has to be supplied to the liquid before it will boil. If, on the other hand, the vessel is an open one, or so constructed that the vapour is drawn away or used as it is formed, as in a boiler supplying steam to a steam engine, the temperature of the boiling point will remain constant until boiling stops. If the pressure is removed or decreased, the temperature at which the liquid will boil falls correspondingly, the lowest boiling points being obtained under the influence of vacuum. When no special pressure is stated, it is always understood that the pressure of the atmosphere is meant. This question of the relation of pressure and temperature is most important; it is the key to the economical working of all refrigerating machinery, and as such should be thoroughly understood.

Latent Heat of Vaporization. When heat is applied to a liquid in order to turn it into a vapour, part of the heat, as we have seen, remains latent, and is expended in overcoming the cohesion of the molecules of the liquid. This heat is known as the latent heat of vaporization, and varies considerably with the pressure at which vaporization takes place. As the boiling point of different liquids varies, that of some being much higher than that of others, it stands to reason that with a liquid having a boiling point below the usual temperature of the atmosphere, the latent heat of vaporization, or the heat necessary to turn that liquid into a vapour, will be drawn from the objects surrounding it at the time of boiling. These objects, giving up their heat to the liquid, will fall in temperature and become cold or refrigerated, the amount of the refrigeration produced depending on the temperature at which the liquid is boiling. The vapour produced from the liquid contains not only the sensible heat, but also the latent heat of vaporization, and this heat has to be got rid of to some other object before the vapour can again become a liquid If the boiling point of the liquid is above the ordinary temperature of the atmosphere, this heat can be readily disposed of to the atmosphere or to water, and, as the boiling point of liquid can be regulated at will within certain limits by the addition of pressure, all that is necessary, if the boiling point is below the ordinary temperature, is, by the compression of the vapour, to raise its boiling point to such a temperature that it will part with its latent heat to the atmosphere or to water.

Permanent Gases. Permanent gases are things which are not. They used to be defined as gases that could not be liquefied, and at one time gases such as oxygen, nitrogen, and hydrogen, were thought to come under this head. They have, however, yielded one by one. In 1898 Professor Dewar succeeded in liquefying hydrogen, while helium—the last of the so-called permanent gases—was liquefied by the late Professor Kamerlingh Onnes in 1909.

CHAPTER II

THERMODYNAMICS

In this chapter the thermodynamic side of the refrigerating machine is discussed in its general outline and principle. The use of formula and detailed analysis which can be found in many treatises on thermodynamics has, as far as possible, been entirely avoided, and where results are worked out no attempt has been made to secure any greater accuracy than that given by the ordinary slide rule readings. The object has been to develop the arguments leading up to the practical use and application of the Mollier diagram in as simple and as general a form as possible.

The Two Laws. It has been pointed out that heat is a form of energy which can be transformed or transferred into other kinds of energy, but which cannot be destroyed. The science which treats of the laws governing this transformation of heat into mechanical energy is thermodynamics, and is of great importance.

The first law of thermodynamics teaches us that heat and mechanical energy are mutually convertible. When work is turned into heat, or vice versa, every British thermal unit requires for its production, and produces or is capable of producing by its disappearance or transformation, 778 foot-pounds of mechanical energy. This is known as Joules's equivalent.

Although heat and work, when convertible, are equivalent to one another, this conversion can only take place in all cases as far as the conversion of work into heat is concerned. It has doubtless been observed that though heat passes readily from bodies of a high temperature to those of a low, the reverse action never occurs, and it is impossible to convert the whole of any given quantity of heat into work, the reason being that heat cannot produce mechanical work without suffering a fall in temperature. During this fall only a portion of the heat is converted into work. The rest disappears as heat at a low temperature, and becomes unavailable for use, so that what is really used is not the energy contained in the heat, but its availability, and though energy may exist, it is of no use if non-available. This explains the second law of thermodynamics, which says that the unavailable heat of a cold body cannot be conveyed directly to the available heat of a hot one, unless under peculiar circumstances, with which the doing of work at some period or other is inseparable.

Heat and Work. When a substance is heated its molecular activity is increased, and, though the conversion of heat into work can take place in many ways, the most common method is to take advantage of the pressure produced by the molecular activity of a gas due to its having been heated. If gas in this state is introduced behind a piston, the molecules will, in their efforts to get away from each other—that is to say, to each occupy a larger space—exert a pressure upon the piston and move it forward. At the same time as the piston moves and does work, the energy of the molecules will become less, and the temperature and pressure of the gas will fall. The doing of work is essential and, as has already been stated (Free Expansion), there will be no perceptible change in temperature unless work is done by the piston in moving.

A gas can be compressed or expanded in many ways, the most important being either without the subtraction or addition of heat, when its temperature will be changed (adiabatic), or with the loss or gain of heat, to such an amount that its temperature remains constant (isothermal). When heat is expended in doing work on a piston in a cylinder, it enters the cylinder at a high temperature and leaves it at a low one ; the heat which is discharged as unavailable for use is less than the heat which entered, by the heat equivalent to the mechanical work done in moving the piston. The heat engine, however, is theoretically a reversible machine, and the mechanical work done is the exact amount of work which, if the machine were reversed, would suffice to restore the heat discharged, as unavailable, to its original temperature, but no more ; for, were it to raise the heat to a higher level of temperature than it was originally, the second law of thermodynamics would be violated.

Adiabatic Expansion and Compression. If the heat in a reversible heat engine was restored to its original condition without the addition of external heat, adiabatic expansion and compression would have taken place, the expansion being the adiabatic conversion of heat into work, the compression the adiabatic conversion of work into heat.

Isothermal Expansion and Compression. If, on compression, the temperature is to remain constant, the heat expended in imparting energy to the piston must be replaced by heat drawn from some external source. This may also be reversed, and the work done by the piston be again converted into heat, by making it force the piston back and so compress the gas. Now, when work is done by the piston, the heat which was taken in from an outside source in order to keep the gas at a constant temperature will again appear as heat, and will, therefore, have to be removed to some outside source before the temperature of the gas will become what it was at first.

If this cycle is carried out, and the gas is restored to its original pressure without change of temperature, isothermal expansion and compression will have taken place, the expansion being the isothermal conversion of heat into work, and the compression the isothermal conversion of work into heat, and, as everything has been restored to its original condition, no energy has been gained or lost.

Unavailability. Though by this strictly reversible method we obtain the maximum conversion of heat into work, and vice versa, it is obviously of no use for a continuous conversion, for if the work produced from heat has again to become heat, no energy is available for outside application, and we are no better off at the end than when we started. Heat cannot be converted continually into work unless the gas (or other working substance) undergoes a fall of temperature in the process. Even then the whole of the heat imparted to the medium is not available for use as work, however low the temperature to which it falls, unless absolute zero is reached, and as this is practically impossible, there is still molecular energy left in the medium when it is discharged.

If, therefore, we heat the medium from some source of heat, such as coal, this unavailable energy has to be discharged to some substance of a lower temperature than itself, such as the atmosphere or water. It naturally follows that the contrivances or engines which make use of the heated medium will be working under the most perfect conditions when they are abstracting the greatest amount of heat from the medium during its fall from the high temperature to the temperature of discharge, and that if this process is reversed, and heat is raised from the low temperature to the high temperature, the greatest efficiency of the machine will be obtained when the heat is taken in at the highest possible low temperature and discharged at the lowest possible high temperature.

Carnot's Cycle. In any cycle the medium always returns to the same condition as that from which it started, and so may be used continuously over and over again. Carnot devised an ideal cycle, which is reversible. This reversibility is the test of perfection in a heat engine, but, to obtain it, every expansion of the medium must be resisted in such a way that by reversing operations the gas may be again compressed. In other words, there must be no free expansion, and heat must never be allowed to pass between bodies at sensibly different temperatures.

In Carnot's ideal cycle it is assumed that there was a cylinder containing a piston, and a given volume of gas as a medium, and that the cylinder and piston were incapable of receiving or giving up heat except at one particular place, where they could be brought into contact either with a source of heat or a cold body at will. Suppose them to be in contact in the first place with a source of heat, and then follow the cycle. First the piston is moved forward, and the gas expanding draws its heat from the source of heat, so that its temperature remains constant (isothermal expansion). Now the supply of heat is cut off, and the piston is moved forward again in the same direction. The gas expands while doing work, and falls in temperature (adiabatic expansion) until it is of the same temperature as the cold body to which it is now connected.

The piston is now forced inwards in the reverse direction, and, as the gas is compressed, the heat of compression is withdrawn by the cold body, and the temperature remains the same (isothermal compression). The cold body is now cut off, the piston still further forced down, and the gas, being compressed, is raised in temperature until it again reaches the temperature of the source of heat (adiabatic compression), and the process is complete. This is the cycle for the heat engine, but it can be readily reversed, and the gas allowed to expand at the low temperatures—in this stage taking heat from the cold body—and then being compressed adiabatically till its temperature reaches the higher value, and so on. This would be a cycle for the refrigerating machine, the two being as follows—

Heat Engine.	*Refrigerating Machine.*
1. Piston rises, gas absorbs heat from hot body and remains at constant temperature (isothermal expansion).	1. Piston rises, no heat is absorbed and temperature falls (adiabatic expansion).
2. Piston rises, no heat is absorbed, gas expands, temperature falls (adiabatic expansion).	2. Piston rises, gas draws heat from cold body, temperature remains constant (isothermal expansion).
3. Piston falls, gas gives up heat to the cold body, temperature remains the same (isothermal compression)	3. Piston falls, no heat is absorbed and temperature rises (adiabatic compression).
4. Piston falls, no heat is absorbed and temperature rises to original (adiabatic compression).	4. Piston falls, gas gives up heat to the hot body and remains at constant temperature (isothermal expansion).

In a heat engine the relation between the heat *H* supplied to the engine and the work *W* got out of it is as follows—

$$\frac{\text{Work}}{\text{Heat}} = \frac{\overset{T_1}{\text{The temp. at the stop valve}} - \overset{T_2}{\text{the temp. of the exhaust}}}{\underset{T_1}{\text{The temperature at the stop valve}}},$$

or supposing the pressure at the stop valve to be 100 lb. on the sq. in., and at the exhaust 15 lb. on the sq. in.; the temperature of 100 lb. steam in the former case is 337° + 460°

= 797° F. absolute. At atmospheric pressure it is 213° + 460° = 673° F. absolute.

Therefore $\frac{797 - 673}{797} = \frac{124}{797}$, or as 124 is to 797. The consideration of this brings us back to the fact that heat cannot all be turned into work unless it is exhausted at the temperature of absolute zero.

The law reversed for a refrigerating machine would be—

$$\frac{\text{Heat}}{\text{Work}} = \frac{\overset{T_0}{\text{The temperature of the refrigerator}}}{\underset{T}{\text{The temp. of the condenser}} - \underset{T_0}{\text{the temp. of the refrigerator}}}.$$

These formulae show the fact that the refrigerating machine is the exact opposite to the heat engine, and, as before stated, the greatest amount of refrigeration can be performed when there is the smallest difference between the temperature of the refrigerator T_0 and of the condenser T_1. As this difference increases, the work becomes more and the refrigeration less.

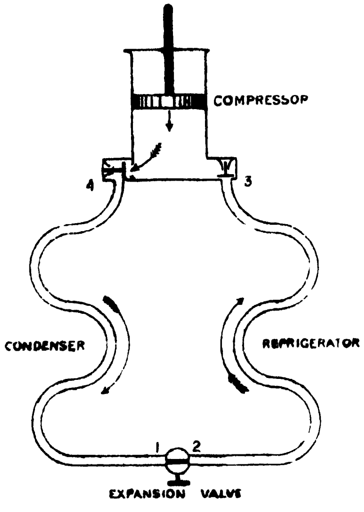


FIG. 2

The Actual Refrigerating Cycle. The cycle of a refrigerating machine is shown diagrammatically in Fig. 2 adjoining. The refrigeration or cooling is entirely effected by the change in state of the working substance in the evaporator, the latent heat of evaporation being taken up from the brine, air, or other medium in contact with the coils or vessel in which it evaporates. If a fluid with suitable characteristics could be obtained sufficiently cheaply, it would only be necessary to evaporate this in a suitable apparatus to effect refrigeration and to allow the gas to escape. The compressor and condenser may, therefore, to some extent be considered as devices to collect the gas coming from the evaporator to compress and liquefy it and enable the same supply to be continually passed through the working cycle.

In a complete refrigerating machine the compressor withdraws the fluid in the form of vapour from the evaporator at the same rate as it is admitted through the expansion or regulating valve. The weight of liquid which will pass through the valve in a given time is largely determined by the difference in pressures on the two sides, and by the area of the valve opening, so that as the valve is closed down a smaller weight of liquid is passed through in a given time or, as it is opened up, the weight of liquid passed through in a given time is increased.

Neglecting the fall of pressure as the refrigerant flows along the pipes, the whole may be considered as being divided into two parts—the refrigerant in the condenser on the left-hand side of the figure being all at one pressure, while that in the evaporator on the right-hand side is all at another pressure, the difference in pressure being maintained by the action of the compressor, and the pressure in the evaporator being controlled by varying the rate of flow through the regulating valve.

At point 1 the substance is in a liquid state at a given temperature and pressure ; in passing through the regulating valve to the low pressure side a portion of the liquid evaporates and the temperature always falls. At point 2 there is a mixture of gas and liquid, and on reaching the outlet of the evaporator at point 3 the liquid may have entirely evaporated, leaving the vapour in a dry saturated state. It may contain and carry with it a certain proportion of liquid if the evaporation has not been completed, or if evaporation has been completed the vapour may be superheated to a temperature above that corresponding to its saturation pressure. The compression which ensues in the compressor is supposed to take place adiabatically, and the result is that the temperature and pressure are very much higher at 4 than at 3, whilst the specific volume is less. In the condenser the gas is first of all cooled down to a temperature corresponding to its saturation pressure; the process of condensation then commences and continues until the whole of the substance is condensed by the time it again reaches point 1.

The Use of Diagrams. The indicator diagram that is used to measure the power developed by the expansion of steam or gas in the cylinders of an engine, or the power consumed by compression in the cylinder of a compressor, is probably familiar to everyone. The indicator diagram shows the quantity of work by means of an area drawn to a definite scale, and as heat and work are convertible it is, therefore, a means of interpreting the transformation of heat into energy, and it has the advantage that the diagram can be obtained mechanically and automatically by means of the indicator. The indicator diagram, however, only shows the measure of the external work.

To follow the complete cycle of changes in the state of the working fluid in a refrigerating machine, it is necessary to construct diagrams or charts embodying the heat changes and the thermal properties of the substance, and this can be done by means of the entropy and Mollier diagrams that are referred to later. As the indicator diagram enables an engine performance to be analysed, it is obvious that a diagram which exhibits the whole process of the thermal and physical changes and state of the working fluid has very great advantages as a means of demonstrating and analysing the work of a refrigerating machine.

Functions of State. It has been shown that in the complete cycle of a refrigerating machine the working fluid is continually changing its state. In order to construct a diagram to incorporate and exhibit these varying functions of the state of the substance, it is necessary to know their values at any and every point of the cycle. In recent years a great deal of investigation and experimental work has been carried out on the properties of the fluids used for refrigeration, and the data that are now available may be regarded as having very small limits of error, and certainly as being sufficiently accurate for all practical problems arising in connection with refrigerating machines.

The functions of the state of the working fluid are—

- (*a*) The pressure (P.).
- (*b*) The temperature (T.).
- (*c*) The volume (V.).
- (*d*) The entropy (ϕ).
- (*e*) The internal energy (U.).
- (*f*) The total heat (I.).

The four latter functions require for their definition a unit of weight, and are reckoned per pound (or other weight unit).

The state of the substance can be fully defined by giving either the pressure or the temperature, and any one of the four remaining functions.

Entropy. This function may be described as the quantity of heat which a substance takes in or gives out during a change of state, divided by the absolute temperature at which it is taken in or out. In a reversible process the entropy has the same value at the end of a cycle as it had at the beginning.

In the consideration of the cycle of operations for refrigeration it is only the changes of entropy that are of interest, and it is usual to take a purely arbitrary zero (usually 32° F. or 0° C.) and to assume that the entropy of the substance in a liquid state is zero at that temperature. In an entropy diagram the co-ordinates are the absolute temperature and the entropy. The description can be more clearly defined by means of an example and diagram.

If heat is applied to a liquid that is at some temperature below its boiling point, it is first heated up to that point. The temperature then remains constant whilst the liquid evaporates, and during this period the substance consists of varying proportions of liquid and vapour. When the liquid is completely evaporated the whole of the substance is in a state of a saturated vapour and, heat still being applied, the temperature again rises and the vapour passes into the state of superheat.

Assuming that the pressure throughout the process remains constant, the entropy diagram assumes the form shown in Fig. 3. Here it will be seen that a gain of entropy is in three stages. In the first stage, *AB*, of heating the liquid the temperature rises as heat is taken in, and the slope of the line is a factor of the increase in entropy with the increase in temperature. During the second stage, *BC*, of evaporation the temperature is constant, so that the entropy is represented

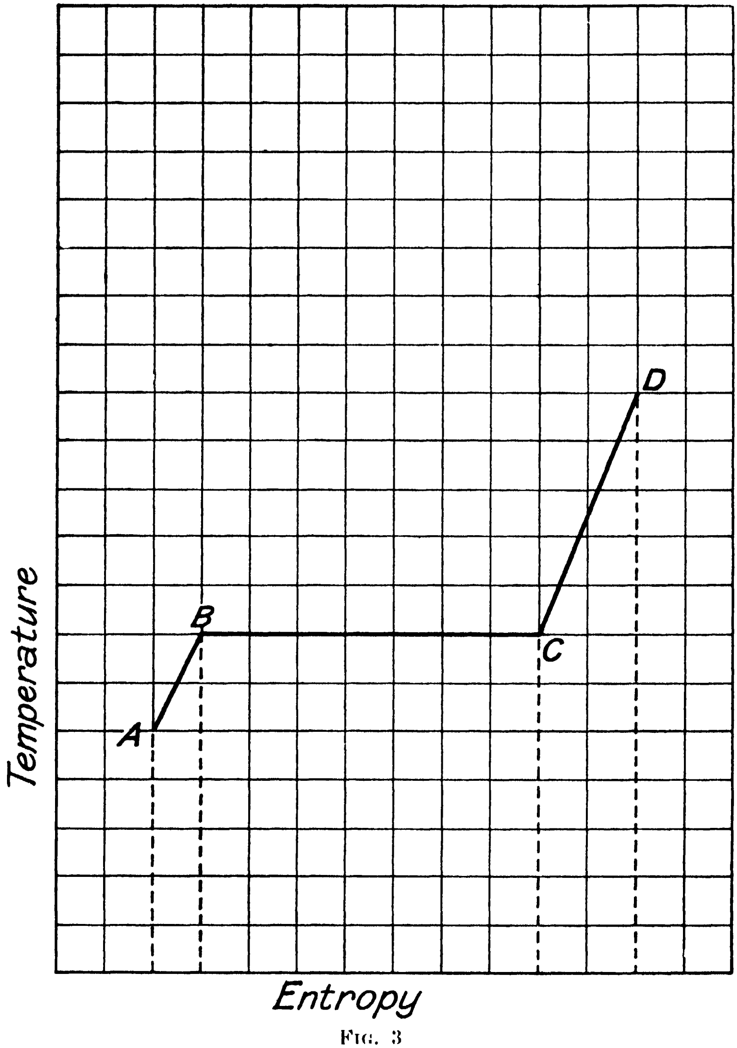


FIG. 3

by an horizontal line, and the length of this line which represents the gain in entropy is the latent heat of the substance divided by its absolute temperature. In the third stage, *CD*, the temperature again rises as heat is taken in. It follows from the definition of entropy that the area under each section, measured from absolute zero, represents the total heat taken in during the process.

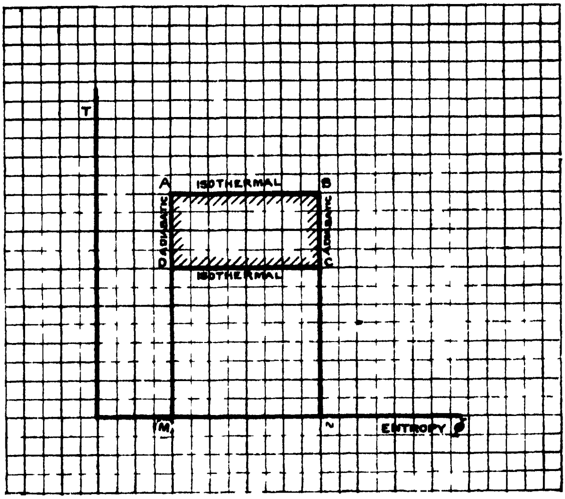


FIG. 4

In adiabatic expansion or compression no heat is taken in or given out. There is consequently no change in entropy, so that adiabatic processes are represented on the entropy diagram by a vertical straight line. In isothermal processes heat is being added or extracted so that there is a change of entropy at constant temperature, and these processes are represented by horizontal straight lines.

The Carnot cycle which has been described has four stages, and consists of two adiabatic and two isothermal stages. Its entropy diagram, therefore, assumes the form shown in Fig. 4. As the Carnot cycle is an ideal one this holds good for any substance.

In the case of a heat engine the heat supplied is represented by the area *ABNM*. The heat converted into work is the area *ABCD*, and the heat rejected which is unavailable is represented by the area *DCNM*. Applied to a refrigerating machine (which is a reversed heat engine) the heat taken in under the lower isothermal is the area *DCNM*; the work effected is shown by the area *ABCD*, and the heat rejected to the condenser is shown by the area *ABNM*.

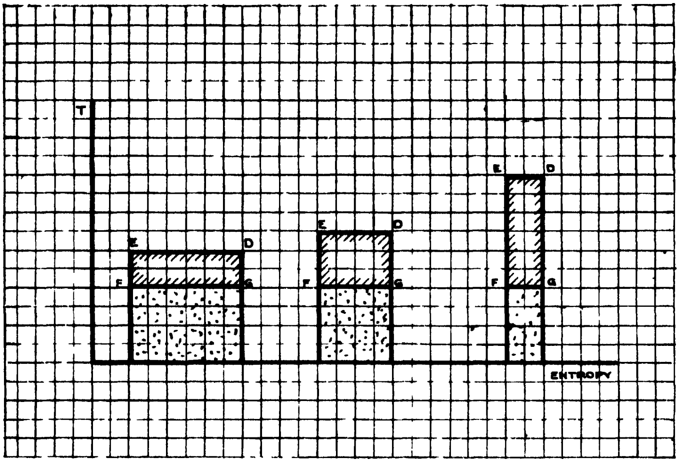


FIG. 5

As the diagram consists of rectangles, their area is a direct function of their height. In a heat engine the performance or the relation of the work done to the heat supplied is $\frac{AD}{AM}$. In a reversed heat engine (or refrigerating machine) the ratio of the refrigeration effected to the power expended is $\frac{DM}{AD}$. Consideration of this fact at once shows how important it is that in a refrigerating machine the range of temperature should be kept as small as possible, and particularly that the lower limit should be no lower than is necessary. Thus, if the rectangle *ABCD* remains the same area but is raised on the temperature scale, the performance will be increased, or if it is lowered on the temperature scale the performance and efficiency will be decreased. The same effect is shown in another way in Fig. 5, where three cycles are shown, each of the same area and with the lower temperature the same in each, yet the refrigerating effects are very different, being equal to the dotted areas, and are therefore inversely proportional to the height *EF* of the work area, and this height is the difference of temperatures. Conversely, with a heat engine it is important that the range of temperature should be as great, and particularly that the lower limit should be as low, as possible.

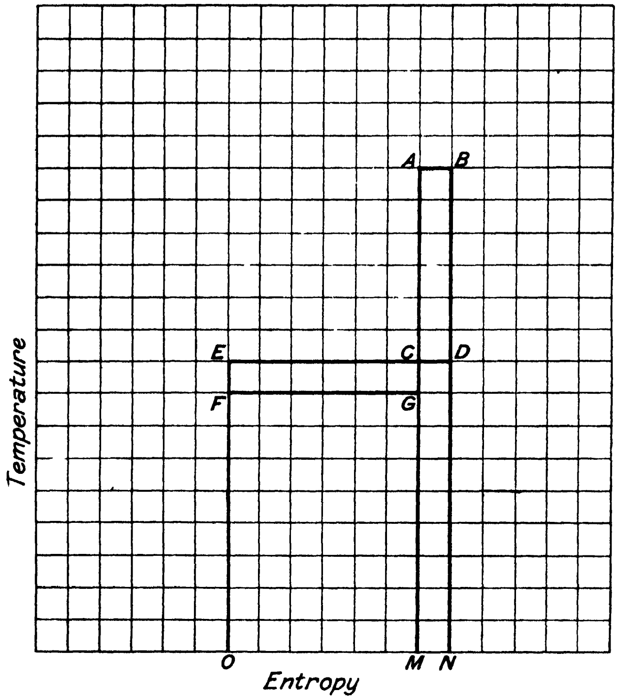


FIG. 6

The entropy diagram can be used to show how, in an ideal cycle, a small quantity of heat at a high temperature can be used to raise a very much larger quantity of heat at a lower temperature.

In Fig. 6 the rectangle *ABNM* shows the cycle for a heat engine, and the rectangle *ECMO* shows the cycle for a reversed heat engine or refrigerating machine. The heat rejected by both the engine and the refrigerating machine is at the same temperature level. The areas *ABDC* showing the work done by the engine, and *ECGF* showing the power expended in the refrigerating machine, are equal, and consideration of the diagram will show it to be obvious that the area *FGMO*, showing the work effected by the refrigerating machine, may be much greater than the area *ABNM*, showing the total heat supplied for the engine.

Machines in actual use do not, however, follow the reversible cycle even approximately. To obtain adiabatic expansion it would be necessary to use an expansion cylinder, but in practice the liquid is subjected to a process of throttling in passing through a regulating valve, and although there may be no heat entering the substance during this process, it is not adiabatic because it is not reversible. Although it does some external work in this stage, it does not do nearly so much as if the expansion cylinder were present, and to return the substance to a state of higher pressure it would be necessary to expend more work upon it than is effected in its expansion, so that if returned it would not be in its original state, but it would be at a higher temperature.

Internal Energy (U). In changing from one state to another the heat entering = increase of U + external work done.

As with entropy, we are only concerned with changes in the state, and an arbitrary starting point or zero is assumed. For any other state we then have U = the heat entering, minus the work done. As we are concerned solely with units of heat, the work done must be understood as its thermal equivalent. The functions of the internal energy itself are so seldom used that reference to it might be omitted but for the fact that it is frequently referred to in tables of properties, and is required for a strict definition of the term "heat content" that follows.

In tables of physical properties of fluids the terms "internal" and "external" latent heat are occasionally used. If 1 lb.

or other unit of a liquid is completely evaporated at constant pressure the volume is increased in a definite proportion, and if it is assumed that the liquid was in a cylinder the increase in volume in moving the piston against constant pressure would represent a certain amount of work done. The latent heat, which is the total heat entering, may, therefore, in accordance with the formula given be subdivided into the external latent heat, which is the thermal equivalent of the work done, and the internal latent heat which represents the balance.

Heat Content (I). This function is also frequently termed "the total heat" and, occasionally, "the enthalpy," and it is possibly the most important and directly useful function in the solution of problems connected with the performance of refrigerating machinery. To use the term "total heat" might imply that the measurement of the heat was taken from absolute zero, but, as with the other functions, we are only concerned with changes in the state from an arbitrary zero, so that the term "heat content" is preferred. The heat content for any state may be defined as $I = U + APV$, where all factors relate to the same temperature, and A being the reciprocal of Joule's equivalent is the factor required to convert work into heat units.

With this definition it will be seen that taking the zero state for internal energy, the heat content has a small, positive value, which is a factor of the volume of the liquid and of the vapour pressure at that temperature, but as internal energy is seldom used, it appears preferable to follow the general practice and to start the values of heat content at the selected zero.

When a substance is heated or cooled at a constant pressure the increase or decrease of heat content is equal to the heat taken in or given out, so that it is a function of the specific heat. In a change of state, such as the evaporation of a liquid, the heat content increases with the proportion of liquid that is evaporated, and when it is completely evaporated the increase of heat content equals the latent heat of evaporation.

In a throttling process, such as the passage of the liquid refrigerant through the small orifice of a regulating valve, it can be proved that there is no change in the heat content. In adiabatic compression or expansion the increase or decrease of heat content is the thermal equivalent to the work done.

The Entropy Diagram. In the discussion of the term it was shown that the co-ordinates of the entropy diagram are the absolute temperature and the function termed entropy.

The formation of one line of constant pressure was shown in Fig. 3. To construct the entropy diagram for any substance the first step is to lay down a series of such lines of constant pressure, taken at regular intervals or steps of pressure, throughout the range of temperature that is covered by the cycle of operations of the substance under investigation. A curve should then be drawn through the points *B*, marking the state of saturated liquid, this curve forming a boundary line separating the region of the liquid on the left from that of mixed vapour and liquid on the right. Another curve should be drawn through the points *C* marking the state of saturated vapour, this forming a boundary line separating the region of mixed vapour and liquid on the left from that of superheat on the right. These boundary curves, if continued upwards, meet in a rounded apex at the critical temperature of the substance. At higher pressures lines of constant pressure lie entirely outside the boundary curve, and have no straight horizontal section.

If the horizontal lines inside the boundary curve are equally subdivided into a number, say, ten of equal sections, and curves are drawn through the points of subdivision, these latter form lines of constant quality, that is to say, they indicate the definite proportions of liquid and of vapour. With a knowledge of the values of the remaining functions, further series of lines can be laid down on the diagram showing constant heat content and constant volume.

From the purely thermodynamic point of view, CO_2 is cosiderably more innteresting than the other substances commonly used for refrigeration on account of the fact that with it the critical temperature comes within the scope of the diagram, and in some cases within the cycle of operations.

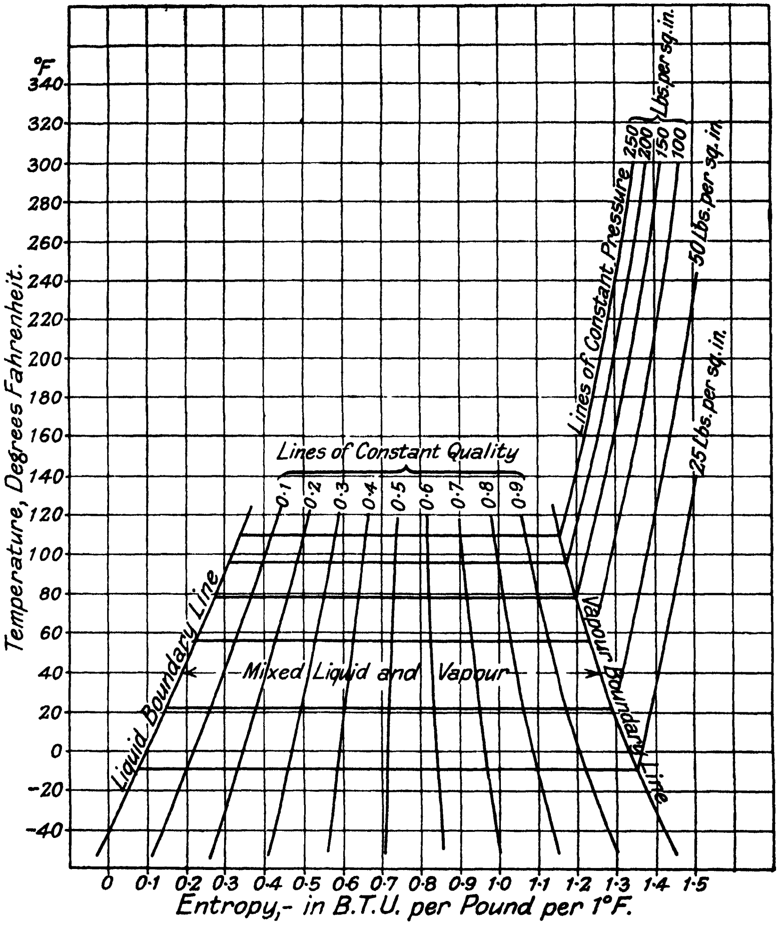


FIG. 7

On account of its near approach to the critical state, the liquid CO_2 does not behave precisely as an ordinary liquid, the volume varying considerably both with the temperature and with the pressure. The entropy and heat content of the liquid are, therefore, governed not only by the temperature, but also by the pressure, and in the entropy diagram the lines of constant pressure for the liquid state to the left of the boundary line diverge from the boundary curve itself.

The volume of liquid ammonia on the other hand is not appreciably affected by changes of pressure within the range of temperatures met with in refrigeration, and the lines of constant pressure for the liquid state coincide so closely with the liquid boundary line that it is impossible to indicate their infinitesimal divergence from it.

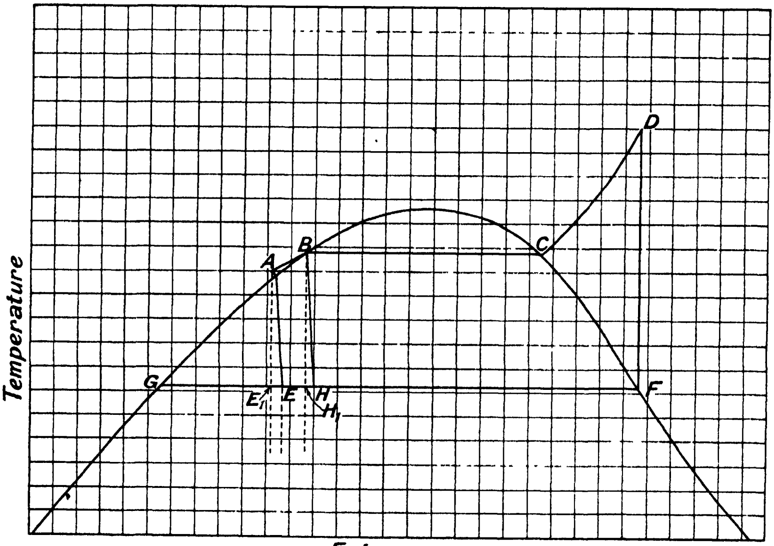


FIG. 8

The entropy diagram for ammonia is shown in Fig. 7, and the cycle of operations for a CO_2 machine in Fig. 8. On this diagram point B represents the state of the liquefied CO_2 in the condenser at a temperature corresponding to its condensation pressure. If it reaches the regulating valve at that pressure the process of expansion is represented by the line of constant heat content BH, the point H being located on the line of constant pressure at which evaporation takes place. At point H the proportion of liquid evaporated is $\frac{HG}{GF}$. Evaporation at constant pressure in the evaporator is represented by the line HF. If the liquid is completely evaporated the point F will, as indicated, lie on the boundary curve for the vapour; if the evaporation is not quite complete, and the vapour passing to the compressor carries some particles of liquid with it, the point F will lie inside, i.e. to the left of the boundary curve, and its position will be governed by the proportion of unevaporated liquid which it carries; while if the vapour is superheated, the position will lie outside, i.e. on the right of the boundary curve, at the point where the line of constant pressure intersects the ordinate of temperature to which the vapour has been superheated. The diagram represents the conditions in the case where the liquid is completely evaporated, without any superheat being added to it. Although this condition does not always obtain in practice, it forms a convenient basis for illustrating the principles.

In any case, the compression in the compressor is represented by the vertical straight line FD originating at the position occupied by the point F. The point D is located by the intersection of this vertical line with the line of constant pressure of condensation, and the temperature to which the vapour is raised by compression is indicated by the position of point D on the vertical scale of the temperature ordinates. The line DC represents the cooling of the vapour at constant pressure to its condensing temperature. At point C condensation commences, and at point B it is completed. If the liquid is cooled below the temperature of condensation, the process is represented by the line BA, and it will be seen that the point A is outside the boundary curve, though in a corresponding diagram for ammonia the line BA and the liquid boundary curve would coincide. Expansion through the regulating valve would in that case be represented by the line AE, and at point E the proportion of liquid evaporated would be $\frac{EG}{GF}$.

The refrigeration effected is represented by the area under the line *EF*, or *HF*, measured from the absolute zero base line. The heat rejected to the condenser is the area under the line *BCD*, or *ABCD*, measured from the absolute zero base line. The work of compression in heat units is the difference of these areas, and is not the area of the figures *BCDFH* or *ABCDFE*.

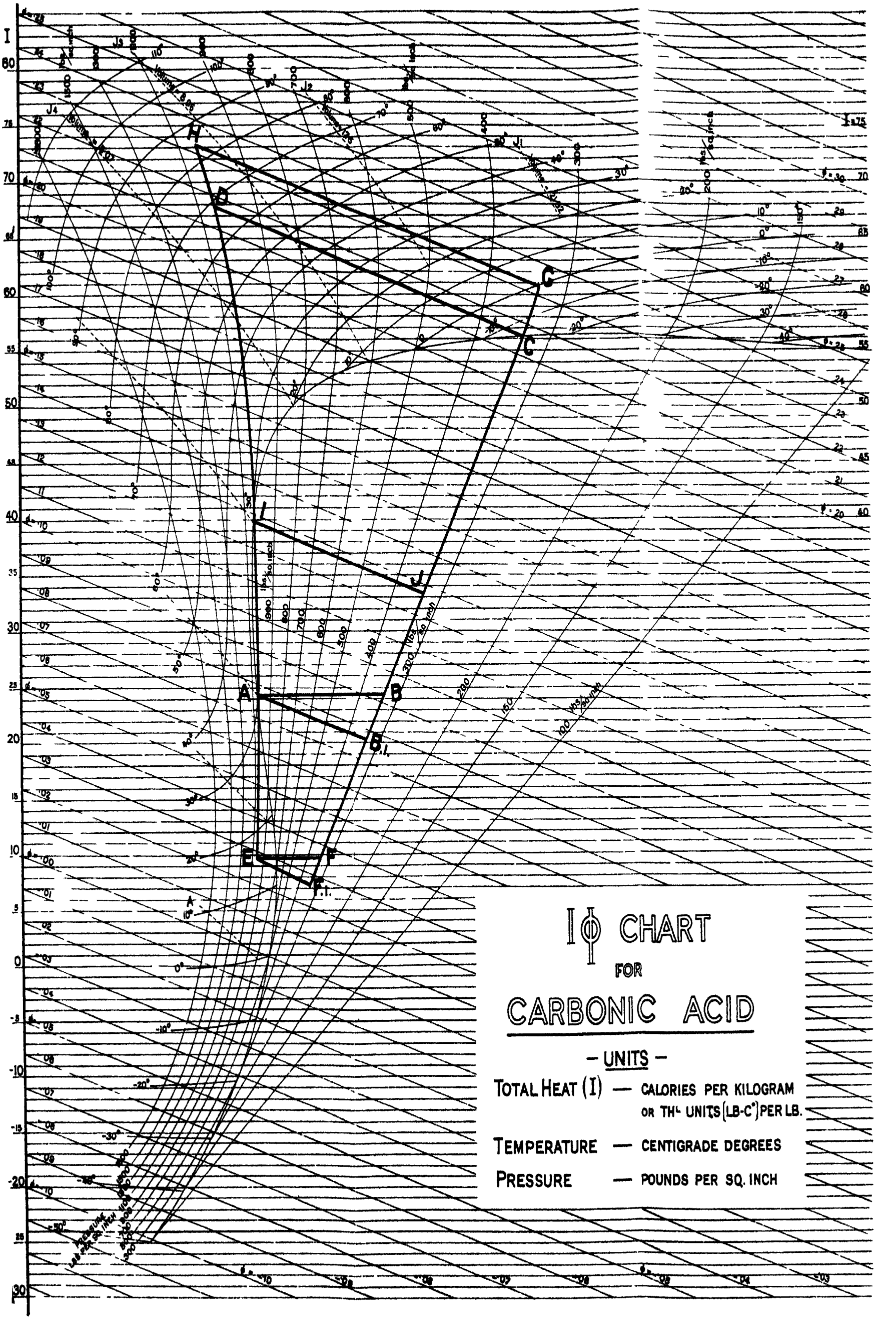
If an expansion cylinder were used in place of a regulating valve, the process of expansion, being adiabatic, would be a vertical straight line extending down from either the point *A* or *B*, as shown in dotted lines, and the points *EI* and *HI* would lie nearer to the liquid boundary line. It will thus be seen that the theoretically possible gain in refrigeration from the use of an expansion cylinder, for the same cycle and expenditure of power, is the area under the lines *E–EI* or *H–HI*, measured to the zero base line.

When lines of constant heat content are drawn on the diagram the numerical values in heat units of the refrigeration effected, and the heat rejected, the work of compression can be obtained by taking the differences between these figures for the heat content at the various points of the cycle of operations. The direct measurement of the heat content is, however, far more readily and accurately obtained from the Mollier diagrams, where the values of the heat content of the substance form one of the two series of co-ordinates.

It is recommended that the Mollier diagram should be used for the study and computation of the results of the cycle of refrigeration, but a knowledge of the entropy diagram is essential for a proper grasp of it.

The Mollier Diagrams. The use of the function (*I*) or heat content as one of the ordinates of a chart is due to Dr. Mollier. The outstanding advantage of this form of chart is that the values of the heat content which represent the refrigeration effected, the work expended in compression, and the heat rejected to the condenser, can be read directly from the scale of the chart, and the ease with which results can be obtained in this way makes this form of diagram invaluable in the study of refrigeration. It is obvious that with heat content as one ordinate, the other can be any one of the remaining

Jenkin and Pye



Iφ CHART

FOR

CARBONIC ACID

– UNITS –

TOTAL HEAT (I) — CALORIES PER KILOGRAM OR THL. UNITS (LB-C°) PER LB.

TEMPERATURE — CENTIGRADE DEGREES

PRESSURE — POUNDS PER SQ. INCH

functions, and several forms were prepared by Dr. Mollier. Two of these are in general use—

(*a*) The heat content entropy diagram.
(*b*) The heat content pressure diagram.

The heat content entropy diagram was used by Dr. Mollier in preparing his original chart for CO_2, and this form was followed by Professor Frewen Jenkin and Mr. D. R. Pye in the chart which is reproduced opposite.* Its great advantage is that as the entropy forms one series of ordinates, all adiabatic processes such as compression are read off along straight lines. In an ordinary form this diagram would become unduly extensive, so that the expedient of skew ordinates has been adopted to keep it within reasonable compass, and as quantities read directly along these skew lines are on a very much larger scale than the vertical one, the values of the adiabatic processes can be read with a correspondingly greater accuracy. The heat content pressure diagram has been adopted by the U.S. Bureau of Standards† for use in conjunction with their tables on the properties of ammonia ; this is reproduced as a folding plate facing p. 42.

The Diagram for Ammonia. In this chart the ordinates are the absolute pressures plotted to a log scale, and the abscissae are the lines of heat content. It will be noticed that in the diagram and in the accompanying tables the zero state for the entropy and heat content of the liquid has been taken at - 40° F. or C. This temperature was selected because - 40° represents the same temperature on both the Fahrenheit and Centigrade scales, and also because it is outside the normal range of temperatures, so that all the values for heat content and entropy are positive, whereas with the usual zero of 32° F. both positive and negative values have to be dealt with. The remaining functions are represented by lines drawn in their proper positions; the liquid line is on the left of the diagram, and the saturated vapour line towards the right.

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* This diagram and Tables VII and VIII at the end of the book are reproduced from Vols. 214 and 213 of the *Philosophical Transactions*, by permission of the Royal Society and of the authors, to whom the author's thanks are due.

† This diagram and Table I at the end of the book are reproduced from Circular No. 142 of the Bureau of Standards of the Department of Commerce, Washington, D.C., to whom the author's thanks are due.

The space between these lines represents the region of mixed liquid and vapour, and lines of constant quality are drawn to indicate the proportions of liquid and of vapour at any point. As the states representing from 20 to 80 per cent of vapour are practically never used, this section has been compressed. In addition, there are families or series of lines showing constant temperature, constant volume, and lines of constant entropy to the right of the diagram in the region of superheat and saturated mixtures.

On the chart facing page 42 is marked the cycle of operations under the conditions specified for the U.S. Standard Ton refrigeration, with extensions showing how the performance can vary, while still coming within the scope of the definition. It will be seen from the tables, or can be read from the chart, that the pressure corresponding to a condensing temperature of 86° F. is 169 lb. per sq. in., and that the pressure corresponding to a temperature of evaporation of 5° F. is 34·3 lb. per sq. in. absolute pressures. Take the following examples, and in—

Case 1. Assume that the liquid ammonia is at the temperature of condensation, i.e. 86° F., and that dry saturated vapour at 5° F. is leaving the evaporator.

At point *A* the ammonia in the condenser is completely liquefied and its heat content is 138·9 B.T.U. per lb. In its passage through the regulating valve the heat content remains unaltered, so that this process is shown by a vertical straight line, extending to point *B* on the line of pressure for 34·3 lb. per sq. in. At point *B* it will be found from the lines of constant quality that ·16 or 16 per cent of the liquid has been evaporated in cooling the remainder to 5° F. The evaporation of this remaining liquid is represented by the line *BC*, the point *C* being on the saturated vapour line, which separates the regions of mixed liquid and vapour from the region of superheat. At point *C* the heat content is 613·3 B.T.U. per lb.; the refrigeration effected by 1 lb. of ammonia is 613·3 – 138·9

= 474·4 B.T.U., and the volume of 1 lb. of vapour is 8·15 cu. ft.

The gas in its condition at point *C* passes into the compressor, and is compressed to a pressure of 169 lb. per sq. in. The compression, being adiabatic, follows a line of constant entropy to the point *D* on the pressure line for 169 lb. per sq. in. At the point *D* the heat content is 712·9 B.T.U. per lb., so that the work done in compression is 712·9 − 613·3 = 99·6.

The performance is, therefore, $\frac{474\cdot4}{99\cdot6} = 4\cdot75 : 1$.

It will be seen from the lines of constant temperature that the temperature at the end of compression point *D* is 210° F., and the lines of constant volume show that the volume of the gas is then 2·36 cu. ft. per lb., the heat rejected to the condenser is 712·9 − 138·9 = 574 B.T.U. per lb., of which 81·4 B.T.U. is required for cooling the vapour to the saturation line, and the balance of 492·6 B.T.U. for the condensation proper.

Case 2. If the gas leaving the evaporator is superheated to 30° F. its state is shown at point *G*, where the line of pressure for 34·3 lb. per sq. in. intersects the line of constant temperature for 30° F. At point *G* the heat content is 628 B.T.U. per lb., so that the refrigeration effected by 1 lb. of ammonia is 628 − 138·9 = 489·1 B.T.U., and the volume of 1 lb. of vapour is 8·7 cu. ft. Compression takes place along the line *GH*, at *H* the heat content is 734 B.T.U., so that the work done is 734 — 628 = 106 B.T.U. per lb., and the performance is $\frac{489\cdot1}{106} = 4\cdot61 : 1$.

The heat rejected to the condenser is 734 − 138·9 = 595·1 B.T.U. per lb.

Case 3. The state of wet compression is obtained when the temperature of the gas delivered from the compressor is its saturation temperature for that pressure. For wet compression the point *I* becomes the end of the compression line and by following the line of constant entropy *IJ* the point *J* is reached on the 34·3 lb. per sq. in. pressure line, at which evaporation must cease. From the lines of constant quality it will be seen that the state of the ammonia at the point *J* is ·89, that is to say at that point 89 per cent of the liquid has been evaporated, the heat content at point *J* is 551 B.T.U. per lb., and the volume is 7·2 cu. ft. per lb. The refrigeration per pound of ammonia is 551 – 138·9 = 412·1 B.T.U.; the work done in compression is 631·5 – 551 = 80·5 B.T.U., and the performance is $\frac{412 \cdot 1}{80 \cdot 5} = 5 \cdot 12 : 1$.

In these three cases the liquid ammonia has been assumed to be at 86° F. If the liquid can be cooled to, say, 60° F. before passing to the regulating valve, its passage through the valve is represented by the line *EF*; its heat content at 60° F. is 109·2 B.T.U. per lb., and the quality at *F* is 0·108. The refrigeration effected by 1 lb. of ammonia for each of the three cases tabulated is increased by 138·9 – 109·2 = 29·7 B.T.U. per lb.

With these particulars the ideal performance under any stipulated conditions can be readily found. Thus for one ton refrigeration, or 200 B.T.U. per minute, the compressor volume and power required with the examples discussed can be summarized as shown opposite.

It will be seen from these figures that wet compression should give the greatest efficiency, but as is explained in Chapter VI, this is not actually borne out in practice. the main reason being that a saturated vapour takes up heat in the compressor more rapidly than a dry gas does. Apart from this it will be found that actual results follow the theoretical figures very closely, and that in well constructed units the performance is remarkably high.

To obtain a reversible cycle it would be necessary to use an expansion cylinder in place of the regulating valve, but as the theoretically possible gain in refrigeration under those conditions with ammonia is only in the neighbourhood of 2 per cent, it will be obvious that the addition of an expansion cylinder would not justify the additional first cost and complication. In all probability these might actually reduce the overall efficiency instead of augmenting it.

With Liquid NH_3 at 86° F.	Case 1.	Case 2.	Case 3.
	Dry Compression.	Superheated Compression.	Wet Compression.
Evaporation—			
B.T.U. per lb.	474·4	489·1	412·1
Lb. per min. per ton refrig.	0·422	0·409	0·485
Cu. ft. per lb.	8·15	8·7	7·2
Cu. ft. per min. per ton. refrig.	3·44	3·56	3·5
Compression—			
B.T.U. per lb.	99·6	106·0	80·5
B.T.U. per ton refrigeration	42·0	43·4	39·05
I.H.P. per ton refrigeration	0·99	1·02	0·92
With Liquid NH_3 at 60° F.			
Evaporation—			
B.T.U. per lb.	504·1	518·8	441·8
Lb. per min. per ton refrig.	0·397	0·386	0·454
Cu. ft. per lb.	8·15	8·7	7·2
Cu. ft. per min. per ton. refrig.	3·24	3·36	3·26
Compression—			
B.T.U. per lb.	99·6	106·0	80·5
B.T.U. per ton refrigeration	39·55	40·9	36·6
I.H.P. per ton refrigeration	0·931	0·963	0·861

The Diagram for CO_2. In the chart the ordinates are the value for the total heat, and the abscissae are the values of the entropy. The abscissae are inclined and, starting from the base line, slope upwards from right to left. The zero state is at 0° C. (or 32° F.).

The diagram is constructed with Centigrade units, calories per kilogram, for the heat content, Centigrade readings for temperature, and pounds per square inch for pressures. The boundary lines for the liquid and saturated vapour states meet at the critical temperature. There are no lines of constant quality, but the quality or proportion of liquid or vapour in the region of mixed liquid and vapour, between the liquid and saturated vapour lines, can readily be estimated by direct measurement. In addition to the co-ordinates of the total heat and entropy, there are lines for constant pressure and constant temperature. A few lines for constant volume are indicated, and these could readily be extended to make the diagram more complete.

On the diagram is marked the same conditions that have been discussed in connection with the heat content pressure diagram for ammonia, and, taking the same cases for CO_2, it will be seen that the pressure corresponding to a condensing temperature of 30° C. (86° F.) is 1,040 lb. per sq. in., and that the pressure corresponding to a temperature of evaporation of –15° C. (5° F.) is 331 lb. per sq. in. absolute pressure. Take the following examples, and in—

Case 1. Assume that the CO_2 is at the temperature of condensation, i.e. 86° F., and that dry saturated vapour at 5° F. is leaving the evaporator. At point *A* the CO_2 in the condenser is completely liquefied and its heat content is 24·5 calories per kilogram. In its passage through the regulating valve the heat content remains unaltered, so that this process is shown by a horizontal straight line, extending to point *B* on the line of pressure, for 331 lb. per sq. in. At point *B* it will be found by estimation that the quality is 0·494, that is to say, 49·4 per cent of the liquid has been evaporated in cooling the remainder to -15° C. (5° F.). The evaporation of this remaining liquid is represented by the line *BC*, the point *C* being on the saturated vapour line, which separates the regions of mixed liquid and vapour from the region of superheat. At point *C* the heat content is 56·1 calories per kilogram; the refrigeration effected is 56·1 - 24·5 = 31·6 calories per kilogram, and it is seen from the tables that the volume of the vapour is 0·2576 cu. ft.

The gas in its condition at point *C* passes into the compressor, and is compressed to a pressure of 1,040 lb. per sq. in. The compression, being adiabatic, follows a line of constant entropy to the point *D* on the pressure line, for 1,040 lb. per sq. in. At point *D* the heat content is 67·7 calories per kilogram, so that the work done in compression is 67·7 - 56·1 = 11·6 calories per kilogram. The performance is, therefore, $\frac{31\cdot6}{11\cdot6} = 2\cdot72 : 1$.

It will be seen from the lines of constant temperature that the temperature at the end of compression, point *D* is

68° C. or 154° F. The heat rejected to the condenser is 67·7 - 24·5 = 43·2 calories per kilogram, of which 27·7 calories are required for cooling the vapour to the saturation line, and the balance of 15·5 calories for the condensation proper.

Case 2. If the gas leaving the evaporator is superheated to 30° F. its state is shown at point *G*, where the line of pressure for 331 lb. per sq. in. intersects the line of constant temperature for 30° F. At point *G* the heat content is 60·5 calories per kilogram, the refrigeration effected is 60·5 - 24·5 = 36 calories per kilogram, and it can be estimated from the tables that the volume is 0·272 cu. ft. Compression takes place along the line *GH*, at *H* the heat content is 73·2 calories per kilogram, so that the work done is 73·2 - 60·5 = 12·7 calories per kilogram, and the performance is $\frac{36}{12{\cdot}7} = 2{\cdot}83$.

The heat rejected to the condenser is 73·2 - 24·5 = 48·7 calories per kilogram.

Case 3. The state of wet compression is obtained when the temperature of the gas delivered from the compressor is its saturation temperature for that pressure. For wet compression the point *I* becomes the end of the compression line, and by following the line of constant entropy *IJ*, the point *J* is reached on the 331 lb. per sq. in. pressure line, at which evaporation must cease.

From the lines of constant quality it will be seen that the state of the CO_2 at the point *J* is ·635, that is to say, at that point 63·5 per cent of the liquid has been evaporated, the heat content is 33·7 calories per kilogram, and the volume may be estimated as 0·14 cu. ft.

The refrigeration is 33·7 - 24·5 = 9·2 calories per kilogram; the work done in compression is 40 - 33·7 = 6·3 calories per kilogram, and the performance is $\frac{9{\cdot}2}{6{\cdot}3} = 1{\cdot}46$.

In these three cases the CO_2 has been assumed to be at 30° C. (86° F.). If, as with ammonia, the liquid can be cooled to, say, 16° C. (60·8° F.) before passing to the regulating valve, the cooling of the liquid at constant pressure is represented by the line *AE* and its passage through the valve by the line *EF*.

Its heat content at 16°C. (60·8° F.) is 9·75 calories per kilogram and the quality at the point *F* is 0·25.

The refrigeration effected for each of the three cases tabulated is increased by 24·5 – 9·75 = 14·75 calories per kilogram.

With these particulars the ideal performance under any stipulated conditions can be readily found. Thus for one ton refrigeration, or 200 B.T.U. per minute, the compressor volume and power required with the examples discussed can be summarized as shown on p. 47.

With a CO_2 machine, whose upper temperature limit is in the region of the critical temperature, the output can be considerably increased by an increase in the pressure of condensation. Thus, taking Case 1, previously referred to, and assuming that the gas is compressed to a pressure of 1,100 lb. per sq. in., the heat content of the liquid becomes 21·6 calories, giving a refrigerating effect of 34·5 calories per kilogram, or 2·9 calories per kilogram more than can be obtained when the pressure in the condenser corresponds to the saturation temperature. The power required by the compressor in compressing the gas to a higher pressure is increased to 12·2 calories per kilogram, and the performance is slightly increased, being $\frac{34{\cdot}5}{12{\cdot}2} = 2{\cdot}82 : 1$.

The theoretical gain obtainable by the use of an expansion cylinder is considerably greater with CO_2 than with ammonia. In passing through a regulating valve the heat content remains unaltered, so that the line representing this process is a horizontal one on the heat content entropy diagram, which is being dealt with. If an expansion cylinder were used the process of expansion, being adiabatic, would be represented by a line parallel to the inclined abscissa. With the liquid at 30° C. this would be represented by the line A–B_1, and with the liquid at 60° F. it would be represented by the line E–F_1. At B^1 the heat content would be 20·5, showing a gain of 4 calories per kilogram, or approximately 12·5 per cent; or, with the liquid at 60° F. the heat content at F^1 would be 7·5 calories, showing a gain of 2·05 calories per kilogram.

A certain amount of experimental work has been carried out with CO_2 machines using an expansion cylinder, but although the theoretical gain is so much greater than with ammonia, the actual improvement in the results has been

	Case 1.	Case 2	Case 3.
With Liquid at 86° F.	Dry Compression	Superheated Compression.	Wet Compression.
Evaporation –			
Calories per kilo.	31·6	36·0	9·2
B.T.U. per lb.	57·0	64·8	16·55
Lb. per min. per ton refrigeration	3·52	3·09	12·08
Cu. ft. per lb.	0·2576	0·272	0·14
Cu ft. per min. per ton refrigeration	0·906	0·84	1·69
Compression –			
Calories per kilo.	11·6	12·7	6·2
B.T.U. per lb.	20·9	22·85	11·34
B.T.U. per ton refrigeration	73·5	70·6	137·0
I.H.P. per ton refrigeration	1·73	1·66	3·23
With Liquid CO_2 at 60° F			
Evaporation –			
Calories per kilo.	46·35	50·75	23·95
B.T.U. per lb.	83·5	91·5	43·0
Lb. per min. per ton refrigeration	2·4	2·19	4·66
Cu ft. per lb.	0·2576	0·272	0·14
Cu. ft. per min. per ton refrigeration	0·617	0·595	0·655
Compression –			
Calories per kilo.	11·6	12·7	6·3
B T.U. per lb.	20·9	22·85	11·34
B.T.U. per ton refrigeration	50·25	50·0	53·1
I.H.P. per ton refrigeration	1·18	1·175	1·245

by no means commensurate either with the gain that might be made in theory, or with the additional cost and complication involved.

In the examples which have been taken, the condensing temperature of 86° F. is very near the critical temperature for CO_2. It may be instructive to take a case with a lower condensing temperature, and also to examine the results of the cycle of operations when the condensing temperature is above the critical point. In the international calories rating, it is specified that the capacity is to be taken when a machine is cooling brine from – 3° to – 5° C., with water entering the condenser at 10° C. and leaving it at 15° C. With reasonably generous surfaces and a condenser either of the submerged or double pipe type, this would mean a temperature of evaporation of – 10° C., a temperature of condensation of 20° C., and a temperature of the liquid CO_2 of 15° C.

With dry compression the following figures are found—

Heat content of vapour in calories per kilogram	56·0
Heat content of liquid at 15° C. in calories per kilogram	10·4
Refrigeration effected in calories per kilogram	45·6
Heat content at end of compression in calories per kilogram	63·0
Heat content of vapour in calories per kilogram	56·0
Heat content of compression in calories per kilogram	7·0

$$\text{Performance} \quad . \quad . \quad . \quad \frac{45\cdot 6}{7\cdot 0} = 6\cdot 5.$$

The variation in performance with incomplete evaporation, or with the vapour in a superheated state, can readily be ascertained, and it will be found that whereas with ammonia wet compression gives theoretically the best performance, this is obtained with CO_2 with practically dry compression for all temperature conditions.

In the early days of CO_2 machines, before the thermodynamics of the cycle of operations were fully appreciated, it was often asserted that effective refrigeration must practically cease at the critical point or higher temperatures. Actually this is not the case, and by plotting curves for performance, based on a series of observations from the diagram, it will be seen that the curve is a smooth one with no break at the critical temperature, although the falling off in the performance, which is the index of efficiency, is very much more rapid with rising condensing temperatures than it is with ammonia or the other substances in common use, whose critical temperatures are considerably removed from the normal range of working.

Thus, to take an extreme case, assume that the liquid CO_2 is at a temperature of 95° F. = 35° C., that the vapour is compressed to 1,300 lb. per sq. in., that the pressure of evaporation is 300 lb. per sq. in., corresponding to a temperature of about 0° F., and that the liquid is completely evaporated so that dry compression results, there results—

Heat content of vapour in calories per kilogram	56·2
Heat content of liquid at 1,300 lb. per sq. in. and 35° C. in calories per kilogram	24·5
Refrigeration effected in calories per kilogram	31·7
Heat content at end of compression in calories per kilogram	71·5
Heat content of evaporation in calories per kilogram	56·2
Heat content of compression in calories per kilogram	25·3

Performance . . . $\frac{31\cdot 7}{25\cdot 3} = 1\cdot 25$.

CHAPTER III

HISTORICAL

THERE is little profit, from a practical point of view, in going deeply or minutely into the history of refrigerating or any other kind of machinery. From the present day standpoint a historical survey can only be of academic interest, and, therefore, a very brief reference to the early workers and early machines will be all that is called for in a volume such as this. As refrigerating machinery is now restricted to three, or at the most four types, each having its well-recognized advantages and disadvantages, it will be useful, before enumerating the early machines, to indicate the several systems upon which the various inventors exercised their talents.

These are clearly divided into three distinct classes, as follows—

1. The chemical refrigerator or freezing mixture.
2. Machinery using a gas (air) which is compressed, partly cooled, and then reduced to a low temperature by expansion while doing work, the low temperature thus produced being employed to abstract heat from the substance it is desired to cool.
3. Machinery which produces its refrigerating effect by the evaporation of some volatile liquid having a low boiling point.

Class I. The Freezing Mixture

That a low temperature could be produced by the combination of two solid bodies uniting chemically to form a liquid has probably been known by scientists for centuries. In 1762 a mixture of crushed ice or snow and salt was employed by Fahrenheit when he obtained his zero temperature and placed the freezing point of water at 32. The action of the frigorific mixture is due to the absorption of latent heat. When, for instance, certain solid substances, such as ice and salt, are brought together, the tendency to combine and melt is so great that heat absorbed in the action cannot be supplied from external sources as quickly as it is required by the two substances. Consequently, the internal heat of the two substances themselves is drawn upon, they become chilled, and the temperature drops until the heat drawn from the two sources—external and internal—is sufficient to keep pace with the rate of melting. Several attempts have been made to apply these properties on a commercial scale, and Sir William Siemens invented and patented a machine in which cold was produced by the heat absorbed by the fusion of calcium chloride and water. The machine was made, and produced ice, but was abandoned as expensive and impracticable. Tocelli invented a machine, using a mixture of ammonium nitrate and water, and the same agent has been used in other machines. Apart, however, from the popular objection to the use of chemicals in connection with ice making, the machines were inefficient and cumbersome, and have long ago given place to mechanical methods. Freezing mixtures are, however, still used in the laboratory, where they are invaluable for quickly producing low temperatures for experimental purposes.

Class II. Machines Using Gas, or Cold-air Machines

Until about 1892 the cold-air machine was, at any rate in England and the Colonies, the most commercially successful method of producing low temperatures. The first cold-air machine of which there is any record, or which attained any success, was invented about the year 1845 by Dr. John Gorrie of Apalachicola, Florida, U.S.A., and a monument has been erected in that town to his memory, as a pioneer of the refrigerating industry, by the members of the Southern Ice Exchange.

Gorrie's machines worked on what is known as a closed cycle. The air when cooled by expansion, instead of being discharged into the cold chamber as in the open-cycle machine, was used to cool brine, which in its turn was used to cool the cold chamber or to make ice, the expanded air being recompressed and used over again. The machine has been described as follows by Mr. Coleman*—

> The first machine consisted of a cylinder about 8 or 9 in. in diameter for compressing air, and of another cylinder about two-thirds the capacity of the first, in which the air was expanded. A jet of water was injected into the compressing cylinder, and the compressed air was discharged into a vessel surrounded by cold water, where it was further cooled and the injected water allowed to settle ; the air was then admitted to the expansion cylinder, and, whilst expanding, a jet of salt water was injected. This salt water being drawn off, was allowed to circulate round vessels containing the fresh water to be frozen.

In 1861 Kirk's machine appeared and was fully described in a paper read before the Institution of Civil Engineers in 1874.† This machine, which also had a closed cycle like Gorrie's, was a practical success, and was used in several places, notably at Bathgate near Edinburgh, where it replaced one of Harrison's ether machines, and in Hong Kong, where it was used for making ice.

In 1868 Postle invented a cold-air machine, and in 1869 two German engineers, Windhausen and Nehrlick, invented machines for the same purpose. In Windhausen's machine the pressure of the expanded air was much below that of the atmosphere, and for this reason the machine was large and cumbersome. The necessity of maintaining a vacuum in the cold chambers was also a great disadvantage. Paul Giffard's machine was invented in 1873, and worked on the open cycle ; the air, after expansion, being discharged direct into the chamber containing the articles to be cooled. At this time cold-air machines were receiving the bulk of the attention of inventors. In 1877 James Coleman and John and Henry Bell took the matter up, and the first Bell-Coleman machine was built in that year by the Bell-Coleman Mechanical Refrigeration Co. of Glasgow. This machine aroused considerable commercial interest. With it the refrigerating industry may be said to have been fairly started, as it was used for preserving fresh meat in the passage across the Atlantic.

A somewhat similar machine was fitted on board the

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* *Proceedings Inst. C.E.*, vol. lxviii, p. 152.

† *Proceedings Inst. C.E.*, vol. xxxvii. p. 244.

Strathleven, and in February, 1879, she arrived in London with 34 tons of frozen mutton and beef on board. This was the first meat ever imported from Australia ; for though about the year 1860 James Harrison had sent home a consignment of meat preserved by artificial ice, the ice all melted before the end of the voyage, and the meat had to be thrown overboard.

In 1881 the sailing ship *Dunedin* was fitted out with Bell-Coleman machinery by the New Zealand and Australian Land Co. Mr. Tom Brydone, the manager of the company, was the enthusiastic spirit behind the enterprise, and as he also started the first butter factory, is regarded as the father of the perishable produce export trade of New Zealand. He is buried at Blair Atholl, Perthshire, and a handsome monument has been erected to his memory at Totara near Oamaru. " Brydone Hall," in Dunedin, is named after him, and a similar compliment was paid to his memory by calling the Court containing the perishable produce in the New Zealand Pavilion at the British Empire Exhibition held in 1924 and 1925 by his name. Five thousand sheep, the bulk provided by Mr. Brydone from Totara Station and the balance by Messrs. Murray, Roberts & Co., were frozen and shipped in the *Dunedin.* In a paper read before the Society of Arts in 1895, Sir Montague Nelson gave an interesting account of the voyage. While in port no difficulties were met with but

> Trouble, however, began when the vessel was becalmed in the tropics and the temperature was gradually found to be rising in the 'tween decks in spite of every effort on the part of the engineers to keep it below freezing point. " The hour brings the man," and this time the man turned up in Captain Whitson, in command of the ship, who proved himself worthy of the grateful thanks which he afterwards received from all concerned in the venture, for, had he not been a man of ample courage and resource, there would have been, at any rate, a partially injured cargo to deal with in London. The main air trunk (the trunk conveying the air from the expansion cylinder of the refrigerating machine to the hold) got snowed up, and the captain himself crawled down to clear it out and was successful, but got so benumbed during the process that he had to be hauled out by the heels with a rope. Captain Whitson's lot was not a happy one during this voyage, as in addition to the anxiety of maintaining cold below deck, he was, on certain tacks of the ship, in constant dread of setting the sails and rigging on fire by sparks from the refrigerator engine funnel.

However, in the end all difficulties were overcome, and, after his strangely equipped craft had received much attention in the Channel from passing steamers, which offered towing assistance to what they could only imagine was a disabled steamer, he landed his cargo in splendid order.

The mutton fetched over 6d. per lb., and the possibilities of trade this opened up created considerable excitement in engineering and commercial quarters. About this time Messrs. Haslam of Derby, Messrs. J. & E. Hall of Dartford, and some other makers also started the manufacture of refrigerating machinery. In 1884 Messrs. Haslam & Co., as the result of a legal action, bought up the Bell-Coleman patents, and eventually brought the manufacture of cold-air machines to a state of great perfection.

Cold-air machines were of two classes: (1) those in which the same air was used over and over again without coming actually into contact with the substance to be cooled, or the closed-cycle machine; and (2) those in which the cold air was exhausted from the machine and circulated through the cold stores in which the goods to be refrigerated were lying. These latter are known as the open-cycle machines, and, though practically obsolete, are the only ones which had any extended use. The former class became obsolete many years ago.

Credit to whom credit is due, and it was undoubtedly largely owing in the first instance, to the cold-air machine that modern England has her abundant and good supply of frozen meat, for, though the trade is now carried on by other systems of refrigeration, it was the cold-air machine which originated it and made it possible. In the cold-air machine ordinary atmospheric air is compressed to a pressure of about 50 lb. on the square inch; the air by being compressed is raised in temperature, and the heat is taken out of it by passing it through a cooler, the tubes of which are surrounded by water. From the cooler the air is passed through a dryer, which consists of a series of tubes placed in, and surrounded by, the cold air returning from the cold chamber. In the dryer the compressed air is chilled and any moisture it contains is deposited. The air, still under compression, passes from the dryer to the expansion cylinder, where it expands and in doing so helps to drive the machine. As air which expands while doing work is reduced in temperature, it leaves the cylinder at a temperature of a very considerable number of degrees below freezing point, and goes away through air trunks to the cold room. The dryer is a most important part of the apparatus. In the early days the principal difficulty with cold-air machines was the fact that when the air was expanded in the expansion cylinder, and reduced in temperature, the moisture contained in it was deposited in the form of ice in the cylinder and on the slide valves, choking them or raising them off their seats, and so rendering the cylinder inoperative. The invention and introduction of the dryer overcame this difficulty, and allowed the machine to work smoothly and well.

Unfortunately the cold-air machine is not economical. Professor Ewing* states that when examining the subject he was unable to find any case of a cold-air machine having a coefficient of performance greater than three-quarters of a unit, while the coefficient of a modern vapour compression machine is, under ordinary working conditions, between four and five units or about six times as great, which means that for every thermal unit put into the steam end of a cold-air machine only three-quarters of a unit are extracted from the cold room, while with a vapour compression machine from four to five units† can be extracted for the same expenditure.

Class III. Machinery which Produces its Refrigerating Effect by the Evaporation of some Volatile Liquid having a Low Boiling Point

The earliest machine which produced ice by purely mechanical means came under this heading and was invented as far back as 1755 by William Cullen. It worked on what is known as the vacuum process, the evaporation of the water at the proper temperature being obtained by the use of a high vacuum maintained by an air pump. Owing, however, to the low vapour tension of water, a very perfect vacuum was necessary in order to secure a sufficiently intense refrigeration, and the mechanical difficulty of this led to the introduction, in 1810, of sulphuric acid as an absorbing agent for the water and vapour. This acid, working in conjunction with the vacuum, enabled ice to be made with comparative ease. Cullen's machine, modified, was probably the basis of Vallance's sulphuric acid machine invented in 1824, and of which Edmund Carré's machine, invented about 1850, was an improvement. Carré's machine consisted of a glass vessel containing water which, under the influence of vacuum, and in connection with a supply of sulphuric acid, froze rapidly into a soft spongy mass. The vacuum was produced by a hand air pump, and the water was frozen in about five minutes from starting operations. The machine, when invented, was much used in Paris, and an improved design is still manufactured for domestic purposes. The necessity, however, of renewing the sulphuric acid from time to time probably prevented its more universal adoption, as there was great need, especially in out-of-the-way districts, for a handy domestic ice maker. A few years later Edmund Carré's brother Ferdinand invented an ammonia-absorption machine, which was the forerunner of the absorption machines of the present time. Ferdinand Carré's first machine was exceedingly crude, and consisted only of two vessels—one used as a generator and the other as an absorber. The generator contained the solution of ammonia and water, and, on being heated, the ammonia gas was driven off to the refrigerator, where it was liquefied by water applied externally. On the solution in the generator becoming sufficiently dilute, the heater was removed and the solution was cooled by water, when the liquefied gas in the refrigerator at once began to volatilize, and to be reabsorbed by the cooled dilute solution. In evaporating it absorbed heat from the water to be frozen, which was placed in a recess in the refrigerator. The machine was afterwards vastly improved by inventors in France and Germany, by Reece and Stanley in England, and by Mort and Nicolle in Australia. The improvements consisted of the addition of new vessels and the development of the process from an intermittent one, as designed by Carré, to a continuous one. Reece, in 1876, introduced several notable improvements, particularly the analyser for rendering the ammonia gas anhydrous, and the absorber, in which the gas, after evaporation, was reabsorbed by the dilute solution or weak liquor. In 1870 Mort introduced the interchanger, or economizer, designed to transfer heat from the weak solution leaving the generator to the strong solution entering it from the absorber. Later on Stanley introduced steam coils into the generator.

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* *Howard Lectures*, Society of Arts, 1897.

† This, of course, depends on the temperature range at which the machine is working.

To Eugene Nicolle, working in collaboration with Mort and Morris, belongs the credit, it is believed, of making, in 1867, the first definite designs for the installation of a refrigerating machine on board ship for the purpose of bringing frozen meat from Australia to England; and to Pontifex and Wood belongs the credit of first bringing the absorption machine to a high state of perfection and a considerable state of efficiency. Their designs, greatly improved, are in use at the present day by Messrs. L. Sterne & Co., Ltd., Glasgow.

To return for a moment to the vacuum machine. In 1870 Windhausen, who also invented the cold-air machine previously referred to, patented a vacuum machine, which was to be capable of producing ice direct from the water without the assistance of sulphuric acid, but which was arranged in such a way that sulphuric acid could, if necessary, be also applied. In 1881, after several improvements had been effected, a machine was built and erected at the Aylesbury Dairy Co.'s premises at Bayswater, but was afterwards removed to the Lillie Road, Earl's Court. The machine was designed to produce from 12 to 15 tons of ice per day, and attracted considerable attention, papers describing it being read before the Society of Engineers and the Society of Arts.* The machine has been described as follows†—

> It consists of six slightly tapered ice-forming vessels of cast iron, of circular cross-section, closed at their bottom ends by hinged doors with air-tight joints, into which water is allowed to flow at a regular

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* *Transactions of the Society of Engineers*, 1882, p. 145; *Journal of the Society of Arts*, 1882, vol. xxxi, p. 20.

† *Proceedings of the I. Mech. E.*, 1886, No. 2, p. 207.

rate through suitable nozzles, the cylinders being steam-jacketed in order to allow the ice to be readily discharged. The upper parts of these vessels communicate with the pump through a long horizontal iron vessel of circular section containing sulphuric acid, which, when the machine is in operation, is kept in continual agitation by means of revolving arms. The acid vessel is surrounded with cold water, which carries off most of the heat liberated during the absorption of the vapour. The pump has two cylinders, one double-acting of large size, and a smaller single-acting one. The capacities of these cylinders per revolution are as 62 to 1. The air and whatever vapour has passed the acid are drawn into the large pump, which partially compresses and delivers them into a condenser. Here part of the vapour is condensed by the action of cold water, the remainder passing along with the air to the second pump, where they are compressed up to atmospheric tension and discharged. The advantage gained by the use of a compound pump is due to the action of the intermediate condenser and to the compression being performed in two stages, by which the losses from the clearance spaces in the large pump are rendered much less than they would be if compression to atmospheric pressure were accomplished in a single operation. The effect of the pump is said to be such that a vacuum of half a millimetre of mercury, or about 0·0097 lb. per sq. in., can be continuously maintained, though in actual work about 2½ millimetres, or 0·0484 lb. per sq. in., is as low as is necessary. The concentration of the acid is effected in a lead-lined vessel, in which is a coil of lead piping heated by steam, the pressure in the vessel being kept down by means of an ordinary air-pump. No acid pump is needed, as the transfer from one vessel to another is effected by the pressure of the atmosphere. The comparatively cool weak acid, on its way to the concentrator, is heated in an interchanger by the strong acid returning from the concentrator. Six blocks of ice, each weighing about 560 lb., are formed in about sixty minutes after starting. The charge of acid is said to serve for four makings of ice, after which it becomes too weak and requires to be concentrated.

The great fault of the machine was that the ice produced was opaque and porous, or what is known as rotten, and rapidly melted when exposed to the atmosphere. This objection is inherent to the system, and is caused by the fact that the water, being admitted in the form of spray, freezes into a series of minute globules, which adhere together, but which contain air in and between them. Several attempts were made to overcome this difficulty, but no great measure of success was obtained. In 1878 Harrison invented a vacuum machine, which, though ingenious, does not call for any special mention, and was, it is believed, never used for commercial purposes. Attempts were made to revive the vacuum and sulphuric process in America. Water was introduced into a cylinder, which was under a vacuum and in communication with an "absorbing agent" (sulphuric acid). The water was frozen solid, and was afterwards cut up into convenient pieces by a circular saw. The ice was opaque, and special advantages were claimed for it on the ground of its whiteness. In England opaque ice is, except for the fish trade and similar purposes where it is only wanted to be cold, almost unsaleable, and the vacuum process has disappeared.

The Compression Process

What may be regarded as the forerunner of the modern compression machine was invented in 1834 by Jacob Perkins. The machine was described by Sir Frederick Bramwell,* and has been often illustrated and described in various papers and journals. However, as it occupies such an important place in the history of the science, a further brief description will not be out of place.

Perkins intended the machine to work with sulphuric ether, but, as a matter of fact, the machine never got beyond the experimental stages. During the experiments caoutchoucine, a volatile oil produced by the distillation of caoutchouc, or india-rubber, at a high temperature, was the agent used. In the machine itself there are all the essential parts of the compression machine of to-day. The water to be frozen was contained in a vessel which was jacketed by a second vessel containing the refrigerating agent, and ingress of external heat was prevented by surrounding the two vessels with insulating materials. The gas or vapour caused by the evaporation of the refrigerating agent was drawn off by the compression pump, and was compressed and delivered to the coils forming the condenser. The pressure was sufficient, with the aid of the water circulating round the coils, to cause liquefaction, and the liquid ran off through a valve to be re-evaporated in the jacket of the refrigerator. It was intended at one time to use these machines in an ice factory, but the project fell through, and it was not until twenty-three years later that James Harrison of Geelong, Victoria, improved the compression machine, and, with sulphuric ether as an agent, brought it into practical use in breweries as well as in the refrigeration of meat and other perishable products. Its manufacture in New South Wales was taken up by Messrs. Russell & Co., of Sydney, and in England by Messrs. Siebe & Gorman. It should be a matter of congratulation and pride to all Australasians that the first really practical compression machine was invented by an Australian engineer, who thus paved the way for the enormous developments that have taken place in Australasia due to the frozen meat industry. It has been noted that Dr. Harrison sent the first consignment of meat to this country preserved by artificial ice made by his machine, and it is to be hoped that in due time his labours and genius will be honoured by the erection of some similar memorial as has been put up by the Southern Ice Exchange to Dr. Gorrie in the United States. As a refrigerating agent ether is now obsolete. It has many disadvantages, prominent among them being its inflammability. The size of the machine for a given duty was also very large compared with one using ammonia or CO_2, and, as both the forward and back pressures were below that of the atmosphere, difficulty used to be experienced in keeping air from leaking in at the compressor glands. In 1873 Professor Linde introduced the ammonia-compression machine, which is now so well known. Three years later, a machine, working on the compression system and using sulphur dioxide as a refrigerating agent, was introduced by Raoul Pictet of Geneva, and is still in use abroad. Pictet discarded lubrication in the compressor, and was probably the first to use a water-jacket to absorb some of the heat of compression, not only the compressor itself, but also the piston and piston-rod, being cooled in this way.

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* *Journal of the Society of Arts*, 1882, vol. xxxi, p. 77.

The seventies, more particularly in the United States, were pregnant with patents and improvements in refrigerating machinery. It would require too much space to describe the various men and machines at length, but, to select a few out of many, mention must be made of David Boyle, whose career has been ably described by Mr. Skinkle, and who is said to have perfected his designs during the siege of Vicksburg;

Charles Ball, who considerably developed the absorption machine; Ferguson, who designed the first machines for the Frick Co.; and John De la Vergne, who introduced oil-injection and perfected the machine referred to later on.

The Binary System

Yet another system of refrigeration remains to be described. This is known as the Binary or Double Agent System, and the refrigerating effect is brought about either by the use of a liquid, being a compound of two agents, one of which will liquefy at a low pressure and then absorb the other, or by the use of a simple agent which is liquefied partly by compression and partly by absorption.

The principal agent used in the former system is a mixture of ether and sulphur dioxide. It was found, after numerous experiments with other mixtures, that this combination was the most suitable, as the ether possesses at ordinary temperatures an absorbing power for sulphur dioxide of some 300 times its own volume, while at 60° F. the vapour tension of the compound was below atmospheric pressure. A machine using this compound has been used in the United States by De Mota and Rossi.

A machine using a cycle of the second class was introduced in 1869 in Sydney, N.S.W., by Mort and Nicolle, who have been previously referred to. In this ammonia was used with water as an absorbent. The refrigerator contained a strong solution of ammonia and water, and a pump was used to reduce the pressure in this vessel, and so vaporize the ammonia. The gas discharged from the pump was brought into contact with the weak liquor remaining, and was again absorbed, the resulting strong liquor being once more forced to the refrigerator. The machine, however, did not come into general use.

About the year 1884 Pictet, the inventor of the sulphur-dioxide machine, invented a compound agent which was universally known as Pictet's liquid. It was composed of certain proportions of carbon-dioxide (CO_2) and sulphur-dioxide (SO_2), the complete formula for the mixture being

CO_4S. The liquid resulting from this combination has a vapour tension which is much less than CO_2 at all temperatures, and for temperatures above 78° F. is below sulphur-dioxide itself. The liquid, though it attracted considerable attention at the time of its discovery, has not come into general use as a refrigerating agent.

Quite a number of agents have from time to time been proposed, and some used experimentally for refrigerating machines. Among these may be mentioned chloride of methyl, ethyl chloride, ethylic ether, ethylo-sulphurous dioxide (Mota and Rossi's mixture), and an obscure agent called cryogene. Acetylene (C_2H_2) has been proposed as a refrigerating agent; it is said to require a pressure of 720 lb. on the sq. in. to produce liquefaction at 32° F. Its intense inflammability would certainly militate against it. Other agents, such as naphtha, gasoline, etc., have been experimented with, more particularly in the United States, but there, as in England and elsewhere, the only two agents which, except for very small or domestic type machines, have any extended use and which require consideration are anhydrous ammonia (NH_3) and carbon-dioxide (CO_2).

No notes on the history of refrigerating machinery would be complete without mentioning the De la Vergne refrigerating machine and the very prominent part it played in this country in the hands of Messrs. L. Sterne & Co., in the latter part of last century. Some of the machines installed forty years ago are still in service, which speaks volumes for the design, and to the quality of the workmanship put into them.

The essential difference between the De la Vergne machine and those of other makers lay in the fact that a measured quantity of mineral lubricating oil was injected into the compressor at each suction stroke. All the clearance spaces in the compressor were full of oil, which not only lubricated the compressor, but sealed the clearance spaces and took up the heat developed during compression. On the compression stroke, the oil and the ammonia passed away through the delivery valves together. It was essential, in order to avoid the expansion of the compressed gas, that all the ammonia gas should be discharged from the compressor before the oil. On the upstroke this was simple enough, but to obtain the same results on the downstroke presented serious difficulties. These were overcome, however, by an ingenious arrangement.

Two valves were placed one above the other in the lower end of the compressor cylinder. As soon as the pressure got sufficient on the downstroke of the piston, these valves opened to the condenser and the gas passed away through them. As the piston descended it covered first the upper valve and then the lower valve. When the piston was at the bottom of its stroke, however, the upper valve came into connection with an annular chamber in the piston itself. This chamber had valves in its bottom, and as soon as the lower valve was covered, these opened and passed the gas, and then the oil through the annular chamber and the upper valve, and so out of the compressor.

The gas and oil passed away through the delivery pipe to the pressure tank, where they separated, the hot gas passing from the top of the tank and going to the condenser, the oil passing from the bottom and going to the oil cooler. The ammonia gas was liquefied in the condenser, ran off through the small pipes to the storage tank, and from that to the separating tank, where any oil that might have been carried over with the hot gas was finally separated from the liquid. The liquid ammonia passed from this tank to the regulating valve, where it expanded, passed through the expansion pipes, where it took up heat and became a gas, and finally passed to the suction valve of the compressor. The oil, after being cooled, flowed through the oil-strainer, where any impurities were caught, and was again injected into the compressor.

CHAPTER IV

THE PROPERTIES OF AMMONIA, CO_2, AND OTHER REFRIGERANTS

AMMONIA, the agent which, with the exception of carbon dioxide (CO_2), is now almost exclusively used in refrigerating machines, is a combination of nitrogen and hydrogen corresponding to the formula NH_3—that is to say, one volume of nitrogen in combination with three volumes of hydrogen. The composition of ammonia, in parts, by weight, is 14 of nitrogen and 3 of hydrogen. It is an alkali, and in its natural state is a gas. At the pressure of the atmosphere it will not liquefy until it is reduced to a temperature of - 28° F. Its liquefaction at higher temperatures is, in accordance with the law of gases, merely a question of pressure.

Anhydrous ammonia, when pure, is a colourless liquid with a peculiar caustic taste. It is manufactured from ammoniacal liquor treated with lime, and from nitrogen, from the air combined with hydrogen from steam; it can also be prepared from aqua ammonia of 26° Beaumé, or containing 30 per cent of ammonia. In the early days it was made directly from its mineral salts, and was absolutely anhydrous. The price of the liquid manufactured in this way is, however, prohibitive.

The process of manufacture from ammoniacal liquor from gasworks is as follows—

The liquor is heated in a still, column, or boiler by means of steam or fire until the bulk of the sulphuretted hydrogen and carbonic acid is driven off. The remaining partly purified liquor is mixed with lime to take up the remaining sulphuretted hydrogen and carbonic acid. This mixture is agitated in a mixer to prevent the lime settling out, and when the reaction is complete the whole is boiled in a still or boiler and the ammonia driven off. To separate the bulk of the water passing away with the ammonia as steam, the vapours are put through a water-cooled separator and, finally, in order to remove the last traces of water, the ammonia gas is put through or over lime or caustic soda. To liquefy the dried gas it is put through a similar compressor to that used in refrigeration plants, and the anhydrous ammonia is collected in receptacles made specially to stand the necessary pressure.

Ammonia is a definite chemical compound which, as already stated, is composed of one volume of nitrogen and three volumes of hydrogen, and no matter what the source of the ammonia may be, these elements were originally obtained from the air and from water respectively. Its method of manufacture does not affect its properties, and once the combination has taken place—whether in coal, the stomach of a horse,* or in a still—the physical properties of the purified liquid, that is to say its boiling point, latent heat, and stability, must be identical.

The process used by Imperial Chemical Industries for the manufacture of Standard Anhydrous Ammonia is briefly as follows—

Nitrogen is obtained from the air by converting the oxygen associated with it to CO_2 by means of red-hot coke. The hydrogen is obtained from steam, again by the use of red-hot coke, and the mixture of these gases in the right proportions is compressed and purified from everything except hydrogen and nitrogen.

Under high pressure, the hydrogen and nitrogen combine to form ammonia in the presence of specially prepared catalysts. On cooling the gas after passage over these catalysts, liquid ammonia of over 99·5 per cent purity is obtained. The impurities in this anhydrous ammonia are nitrogen, hydrogen, and water. The impure anhydrous ammonia is then fractionally distilled to remove almost the whole of the impurities. The product of the still is 99·998 per cent pure, the impurities here being hydrogen, nitrogen, and water, as before. The utmost care is taken that this product shall not be contaminated after it leaves the still.

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* The reference to the stomach of a horse is not quite accurate, but it serves to point the moral. What actually occurs during the process of digestion is not the synthesis of ammonia, but the breaking up of compounds which are the derivatives of ammonia, into simple compounds which are still derivatives of ammonia.

The incoming cylinders for filling are weighed, completely emptied, and carefully examined for traces of oil, water, etc. They are then heated and evacuated before refilling with liquid ammonia. During the filling operations, the gas space of the cylinder is purged occasionally, by releasing the pressure primarily to cool the cylinder and to make the filling easier, but also to ensure complete absence of all but dissolved traces of inert gases. Each and every cylinder is sampled and analysed before dispatch, and while guaranteed as 99·98 per cent pure, it is stated that the actual purity very seldom falls below 99·995 per cent.

Ammonia prepared by this process is extensively used on the Continent, and in order to satisfy itself that the ammonia was stable as well as pure the German Refrigerating Union arranged with Professor Dr. Von Wartemberg to carry out a series of tests. These were duly reported in *Zeitschrift fur die Gesamte Kalte Industrie.* They show that the ammonia does not decompose appreciably in the arduous conditions of the sefrigerating cycle, and that when subjected to 45 days conrtant heating at 160° C. and a pressure of 20 atmospheres the decomposition was not over 0·01 or 0·1 per cent, even if iron and lubricating oil were present. The ammonia, therefore, would appear to be on all fours with ammonia prepared from gasworks residue. This, it may be added, is precisely the result that would have been anticipated.

Ammonia is stated to have the distinction of being the only volatile alkali known to science. Its critical temperature is about 273° F., and at a temperature of 1,600° F.* it will dissociate into its constituent gases. At a temperature of – 107·86° F. it freezes solid. All these temperatures are beyond the normal range met with in practice, and the refrigerating engineer need not feel perturbed that his plant will be overtaken by catastrophes traceable to the action of these characteristics. Of course, ammonia for use in a compression system should be perfectly free from water and other impurities of any sort, one-twentieth of 1 per cent being all that should be allowed.

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* 1,600° F. is the temperature of practically complete dissociation. The process starts at a lower temperature (about 900° F.) and a gradual change takes place, a definite fraction splitting up at each temperature.

Testing ammonia for impurities requires to be done with great care. Being an unpleasant material to handle, it should not be undertaken without previous experience, and it is best to let a properly qualified analyst with proper appliances at his command do the work when possible. For rough tests

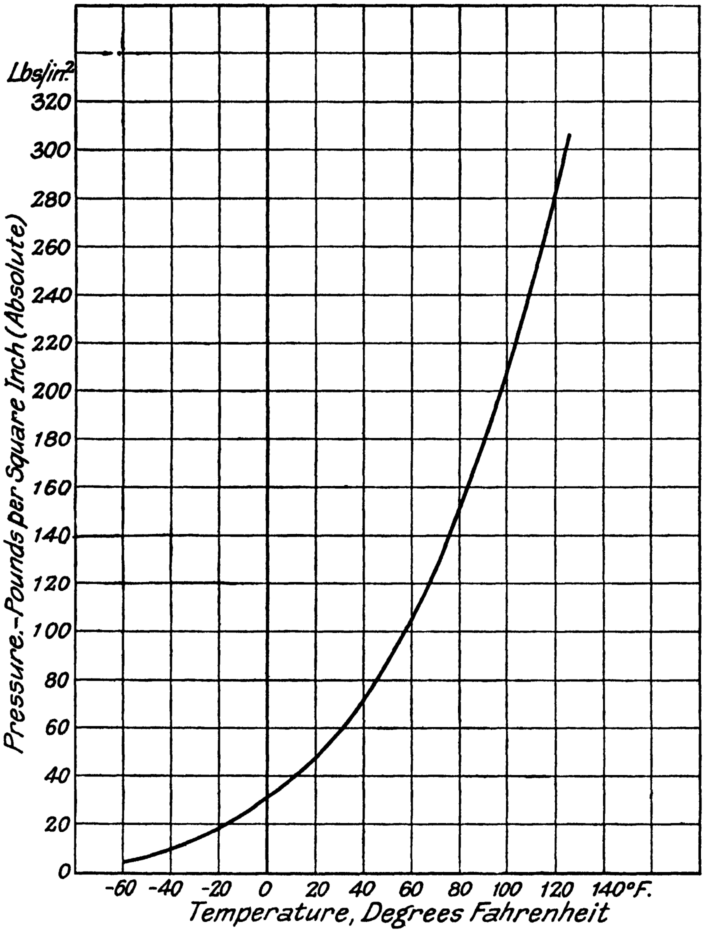

FIG. 9

the usual method is partially to fill a glass test tube with liquid drawn from the system. This test tube should have a cork fitted with a vent pipe to carry off the gas as it evaporates, the other end of the vent pipe being immersed in water which will absorb the gas. If the liquid is pure it will all boil away, leaving no residue, but if it contains impurities these will be left behind in the test tube.

As ammonia is so readily absorbed by water, a serious leak may exist and yet not be discovered. It is advisable, therefore, from time to time to test the water used for condensing purposes, or the brine surrounding the expansion coils, with Nessler's reagent,* the prescription for which is as follows.

Dissolve 17 grams of mercuric chloride in about 300 c.c. of distilled water; dissolve 35 grams of potassium iodide in 100 c.c. of water; add the former solution to the latter, with constant stirring, until a slight permanent red precipitate is produced. Next dissolve 120 grams of potassium hydrate in about 200 c.c. of water; allow the solution to cool; add it to the above solution, and make up with water to one litre; then add mercuric chloride solution until a permanent precipitate again forms; allow to stand till settled, and decant off the clear solution for use; keep it in glass-stoppered blue bottles, and set away in a dark place to keep it from decomposing.

This reagent can readily be obtained from any chemist after the above prescription, and all that is required is to add a few drops to a test glass full of the suspected water or brine, which will assume a yellow colour if ammonia is present at all, or a full brown if it is present in any quantity.

The curve of vapour tensions of anhydrous ammonia, showing graphically the pressure of the gas in pounds per square inch for various temperatures, is given in Fig. 9. Its latent heat of vaporization for various temperatures is shown in the table at the end of the book. It will be noticed that at atmospheric pressure its temperature is - 28° F., and its latent heat of vaporization—that is to say, the amount of heat that it will have to absorb before it will turn from a liquid to a gas—is 589·3. At this pressure 1 lb. of the gas has a volume of 18 cubic feet and the liquid a volume of ·02345 cu. ft.; while the weight of the vapour is ·0555 lb. per cu. ft., and of the liquid 45·65 lb. per cu. ft. the properties of the gas for other pressures and temperatures can readily be found from the table.

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* J. E. Siebel, *Compend of Mechanical Refrigeration.*

A glance at the curve will show how important it is from an economical standpoint to keep the pressure of the gas in the condenser as low as possible, and as this pressure is determined by the temperature of the condenser, it is essential for economical working to have ample cooling water at a low temperature. It will also be noticed that as the pressure of the gas falls the volume increases. At an absolute pressure of 30·42 lb. on the sq. in. the temperature is zero F. and the volume 9·116 cu. ft. per lb.; at an absolute pressure of 13·9 lb. on the sq. in. the temperature is – 30° F. and the volume 18·97 cu. ft. per lb., or more than double. This means that, owing to the increased volume of the gas, the compressor has, at the lower temperature, to take twice the number of strokes per minute, or, if the speed is kept constant, to be twice the size, in order to pass the same weight of gas and do the same amount of work as it would were the higher temperature in use. For this reason, and from this point of view, it is preferable, where possible, to expand the ammonia gas directly into pipes placed in the cold rooms, or liquid to be cooled, instead of effecting a transmission of heat by first cooling and then circulating brine; there are however, cases where this cannot be done, but of these more hereafter.

Ammonia Accidents—First Aid. Ammonia is incapable of being respired, and will produce suffocation if inhaled in any quantity.

Several fatal accidents have at times been caused by the bursting of portions of an ammonia plant, and the consequent escape of large volumes of the gas into the rooms where workmen are employed. In emergencies of this sort the first action is naturally to extract from the room, with the least possible delay, any person who may be overcome. Special ammonia helmets are made for rescue work or to enable work to be carried out in ammonia fumes, and the provision of one of these is a wise precaution on any large plant. If a sponge, towel, or lump of waste is saturated with water and held over the mouth and nose, a room charged with ammonia gas can be entered and the person overcome rescued. The first thing to do is, obviously, to send for the nearest doctor, but life may often be saved and pain lessened by at once administering a glass of beer or a dose of very weak vinegar and water. Either of these will act as an antidote to the ammonia, and the former is decidedly the more popular.

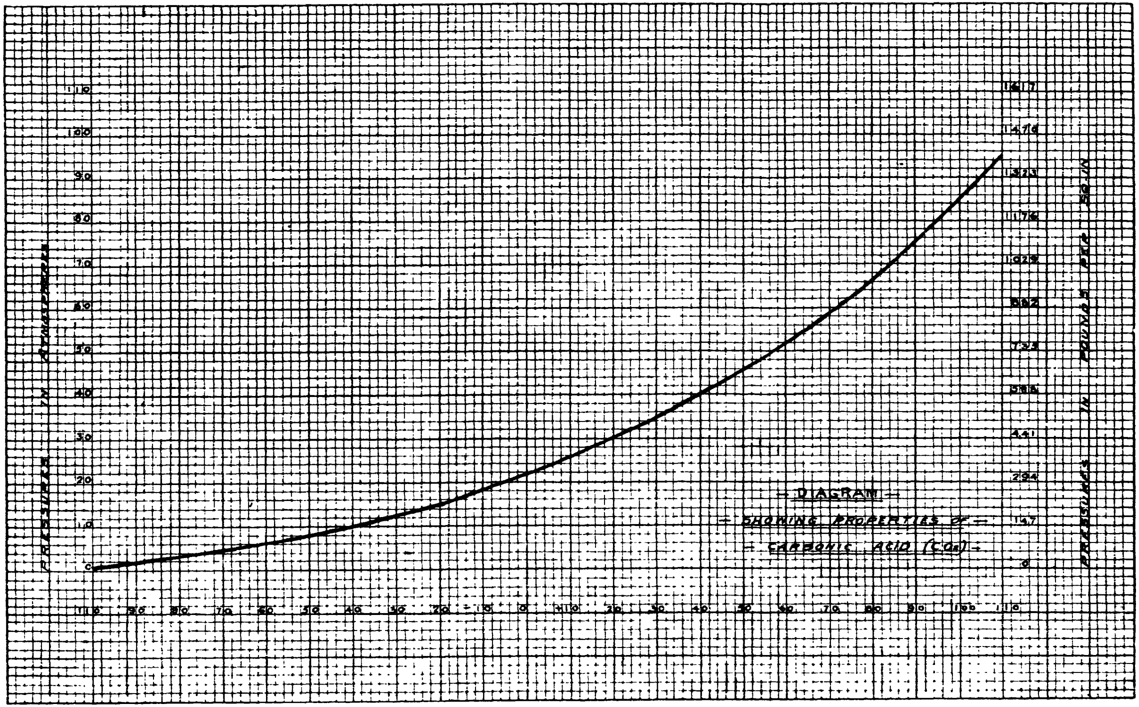
If the eyes are affected they should be bathed with a 1 per cent solution of boric acid, and after a thorough washing a small quantity of vaseline should be inserted under the eyelids. For skin burns tannic acid should be applied on the usual surgical dressing, and it should be changed frequently.

All premises in England in which machinery is used must now have an approved medical cupboard, and in addition to the ordinary dressings, this should be supplied with a bottle containing a 1 per cent solution of pure boric acid, and a bottle of tannic acid.

Carbon Dioxide

This gas, commonly known by its chemical symbol of CO_2, is probably the most familiar of all the gases. It is responsible for the sparkle of champagne, beer, and aerated waters, and exists in nearly all water. In its natural state it is a colourless, odourless gas, and, at a temperature of 32° F. and a pressure of 34·35 atmospheres, it can be converted into a colourless, odourless liquid.

When carbon is burned in oxygen, CO_2 is formed, but if the supply of oxygen is insufficient, carbonic oxide (CO), an extremely poisonous gas, is also produced. The latter will burn with a blue flame, and by its combustion produce CO_2, but pure CO_2 will neither originate nor support combustion. CO_2 does not possess the affinity for water that is common to ammonia, but it will dissolve in about its own volume, forming carbonic acid (H_2CO_3). The solution has a sharp acid taste, and will turn blue litmus paper red. The volume of CO_2 that



— DIAGRAM —
— SHOWING PROPERTIES OF —
— CARBONIC ACID (CO2) —
PRESSURES IN ATMOSPHERES
PRESSURES IN POUNDS PER SQ IN
110
100
90
80
70
60
50
40
30
20
10
0
1617
1470
1323
1176
1029
882
735
588
441
294
147
0
110
90
80
70
60
50
40
30
20
10
0
+10
20
30
40
50
60
70
80
90
100
110

FIG. 10

water is capable of absorbing increases as the temperature falls (*see* p. 466); conversely, it decreases as the temperature rises, and all CO_2 can be expelled if the water is brought to boiling point.

The Properties of CO_2. As a refrigerant CO_2 is very widely used. There was for some years considerable doubt as to its exact properties, but the researches of Professor C. Frewen Jenkins and Mr. D. R. Pye have provided figures which are probably correct within a very small margin of error; these are given in the table at the end of the book and are used throughout this work. The curve of vapour tensions is given in Fig. 10.

The Manufacture of CO_2. The manufacture of CO_2 is carried on in several ways, and, as described later, a large quantity of the pure liquid is obtained from the fermenting tuns of distilleries. The fact that it is heavier than air makes collection in this case easy, and plants both in England and Germany have been erected for this purpose. It can also be readily obtained from other sources.

The usual method of manufacture employed is as follows: The CO_2 is produced by burning coke in the furnaces of boilers. The gases from these furnaces, after being scrubbed, are brought into contact with potash lye, which possesses a strong affinity for CO_2, and absorbs it.

In order to remove the sulphur which is contained in the coke, and which, were it allowed to come into contact with the potash, would form potassium sulphate and render it useless as an absorber of CO_2, the furnace gases are scrubbed on their way to the potash towers by being passed through two towers placed in series and filled with broken marble or limestone. In the first the gas comes in contact with a stream of water which has been heated in an interchanger by the hot CO_2 passing from the boiler. In the second tower the gas comes in contact with a stream of cold water. It then passes to the absorbing towers, which are filled with trays containing broken coke. In these it meets a constant stream of potash lye, which, as before stated, absorbs the CO_2 and allows the rest of the gases to go to waste. The lye containing the CO_2

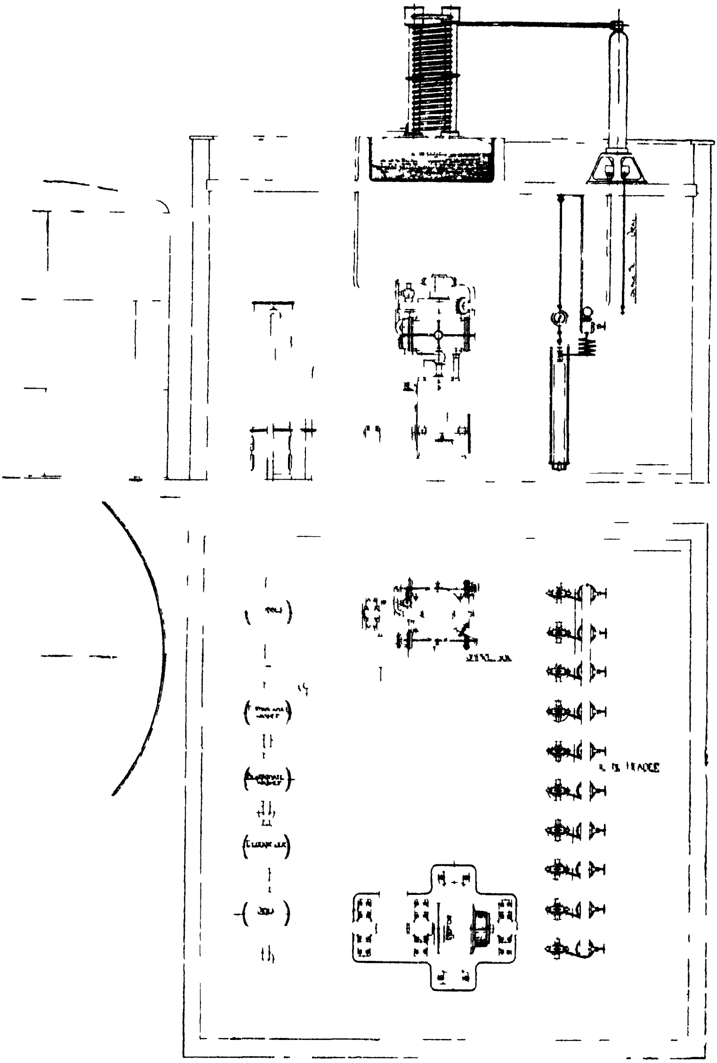


FIG 11

is pumped to the boiler, and on its way passes through an interchanger, where it absorbs heat from the regenerated lye, which, having parted with its CO_2, has just left them.

The boiler pressure is 5 lb. per sq. in., and the lye is passed through the boilers in series, the CO_2 passing off at the top through a liquid trap, which catches any moisture carried over and returns it to the regenerated lye storage tank. As the gas comes from the boilers, it is first passed through an interchanger, where it gives up its heat to the water supply to the first scrubbing tower, and is then collected and passed to the compressors. These deal with the gas in three stages. In the first it is compressed to 25 lb. per sq. in., at which pressure the gas is further purified and robbed of any moisture it may have contained by being brought in contact with calcium chloride. The second compressor raises the pressure to 125 lb. per sq. in. Before entering the third and last compressor, the gas is cooled ; it is then compressed to about 1,000 lb. per sq. in., the exact pressure depending on the temperature of the condensing water, is liquefied, and finally bottled.

A large quantity of the pure liquid CO_2 is obtained as a by-product from the fermenting vats in distilleries. For the collection of the gas these vats are closed in, and are maintained at a pressure of about 1 in. water gauge above atmosphere. They are provided with a U-tube water gauge, which shows by a slight displacement of the water that CO_2 is being generated in sufficient quantities for the collection to proceed without drawing in air. Another method is to use an inverted funnel over the vat with its edges dipped into the liquid like a gasometer. This can be suspended in such a way that as the gas generates it rises and opens the connection to the compressor, or, as the pressure falls, it falls and closes the connection. The gas is collected in a suction pipe common to the various vats. This pipe is connected to a scrubber like that of a suction gas plant where any froth or solid particles are got rid of. The gas then passes to the suction of the first stage of the compressor.

This compressor deserves a special mention as its duties are somewhat difficult. It has to work for a period of sixty

Properties of Saturated Carbonic Acid Vapour

(Transformed from Mollier's Table into British Units)

Pressure in lb. per sq. in.	Temperature (Fah.).	Specific Volume of Liquid in cu. ft. per lb.	Specific Volume of Saturated Vapour in cu. ft. per lb.	Expansion on Vaporization.	Latent Heat in B.T.U.	Heat Equivalent of External Work.	Internal Latent Heat.
P		v'	v''	$v'' - v' = u$	r	APu	ρ
284	− 5	·0161	·3182	·3021	119·86	15·98	103·88
355	+ 9	·0165	·2497	·2332	113·26	15·41	97·85
427	+ 20·7	·0170	·2028	·1858	106·94	14·76	92·18
498	31·2	·0176	·1698	·1522	100·44	14·06	86·38
569	40·5	·0181	·1435	·1254	93·76	13·26	80·50
640	49·0	·0188	·1232	·1044	86·90	12·42	74·48
711	56·7	·0194	·1059	·0865	79·65	11·45	68·10
782	63·8	·0204	·0919	·0715	71·73	10·39	61·34
853	70·3	·0213	·0795	·0582	63·22	9·22	54·00
924	76·7	·0226	·0676	·0450	52·87	7·74	45·13
995	82·6	·0249	·0563	·0314	39·29	5·79	33·50
1,066	88·2	·0307	·0385	·0078	10·51	1·56	8·95

to seventy hours without a stop, and has to do this cheerfully with a varying input and, consequently, output. It is not good to throttle because this reduces the suction pressure, and the ratio of compression in the successive stages is increased and causes a rise in the temperature of the gas which is bad for its flavour. The machine consequently should be fitted with a variable speed motor, or with variable clearance so that its output can be altered without throttling.

CO_2 derived from fermentation contains a number of ethers which, by their odours, make it impossible to use the gas for ordinary purposes, so that it is necessary to purify it. On leaving the first stage the CO_2 passes through the purifying arrangements. Acid towers may or may not be required, depending on circumstances. It is washed with permanganate and bi-carbonate or other salts, dryed with calcium chloride or other drying agents, deodorized by charcoal, and compressed in the second stage of the compressor. It then passes through an intercooler and goes to the third stage, after which it is cooled, condensed, dehydrated, and bottled. The receiving vessel into which the liquefied CO_2 passes from the condenser should have a purge valve to blow off any air or uncondensed gases.

The general arrangement of a CO_2 collecting, liquefying, and bottling plant as above described is shown in Fig. 11.*

Other Gases. Although ammonia and CO_2 are most commonly used as refrigerating agents, there are still some plants constructed for SO_2 and ethyl chloride, and a number for Freon and methyl chloride. These agents do not call for any extended notice, though Freon is coming into extended use. Tables and particulars are given at the end of the book.

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* Messrs. Peter Brotherhood, Ltd., Peterborough, England

CHAPTER V

TYPES OF MACHINES

THE principle of the compression machine has been explained in the introduction and in Chapter II. The same cycle is repeated and the same elements are required whatever refrigerant may be used. There are a great many makers of ammonia compression machines, some of whom also make CO_2 compressors, and there are a smaller number who exclusively make machines to work with CO_2 or other refrigerants in use such as SO_2, and ethyl and methyl chloride.

Whilst compressors can in general terms be subdivided into a few types, such as horizontal double acting machines, vertical double acting machines, and vertical single acting machines, high speed compressors fitted with light disc or ring plate valves and working with forced lubrication to all bearings are now the established practice, and the older slow speed machines are practically obsolete. Though there may be a strong family resemblance between different makes of any one type, all of the many makers have their own constructional features, and all that is necessary here is a brief mention of the principal features of the machines made by some of the leading manufacturers.

In this development of high speed, refrigerating compressors have only followed the general trend of modern engineering practice—the stages have been very similar to those which ordinary air compressors have passed through, and have been largely brought about by the almost universal application of the electric motor, either direct coupled or with a vee-belt drive, as the source of power where electricity is available.

With higher speeds it becomes practical to have the motor direct coupled to the compressor shaft. The space occupied by the machinery and the corresponding foundations are reduced with a reduction in the cost of the building work. Alternatively, it is possible to install a greater refrigerating capacity in a given limited space. At the same time the mechanical lubrication reduces the attention necessary, the lubricating oil consumption, and general wear and tear.

Double-acting compressors of the vertical and of the horizontal type are made by a number of manufacturers, particularly for installations of the larger sizes, but as the illustrations show, the vertical single-acting direct coupled compressor is now a standard pattern for the majority of manufacturers.

Another development that was foreseen and referred to in the second and third editions, is the extending use of two-stage ammonia compressors, for cases where the ratio of compression exceeds the normal, which is about 5 or 6 to 1.

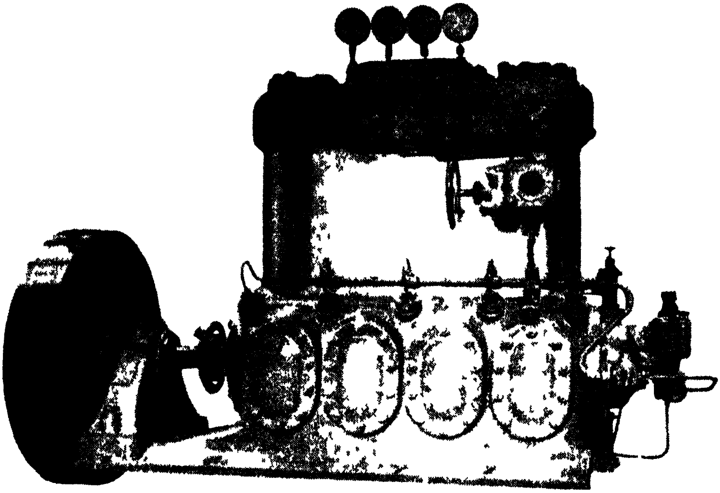

FIG. 12

By the ratio of compression is meant the relation of the absolute pressures on the suction and on the delivery sides of the compressor. Thus, taking the standard conditions for the U.S. tons refrigerating rating for ammonia, the suction pressure is about 34 lb. per sq. in., the delivery pressure about 169 lb. per sq. in., and the ratio is $\frac{169}{34} = 5$ to 1 (approx.). If either the delivery pressure is increased or the suction pressure is reduced the ratio will be increased.

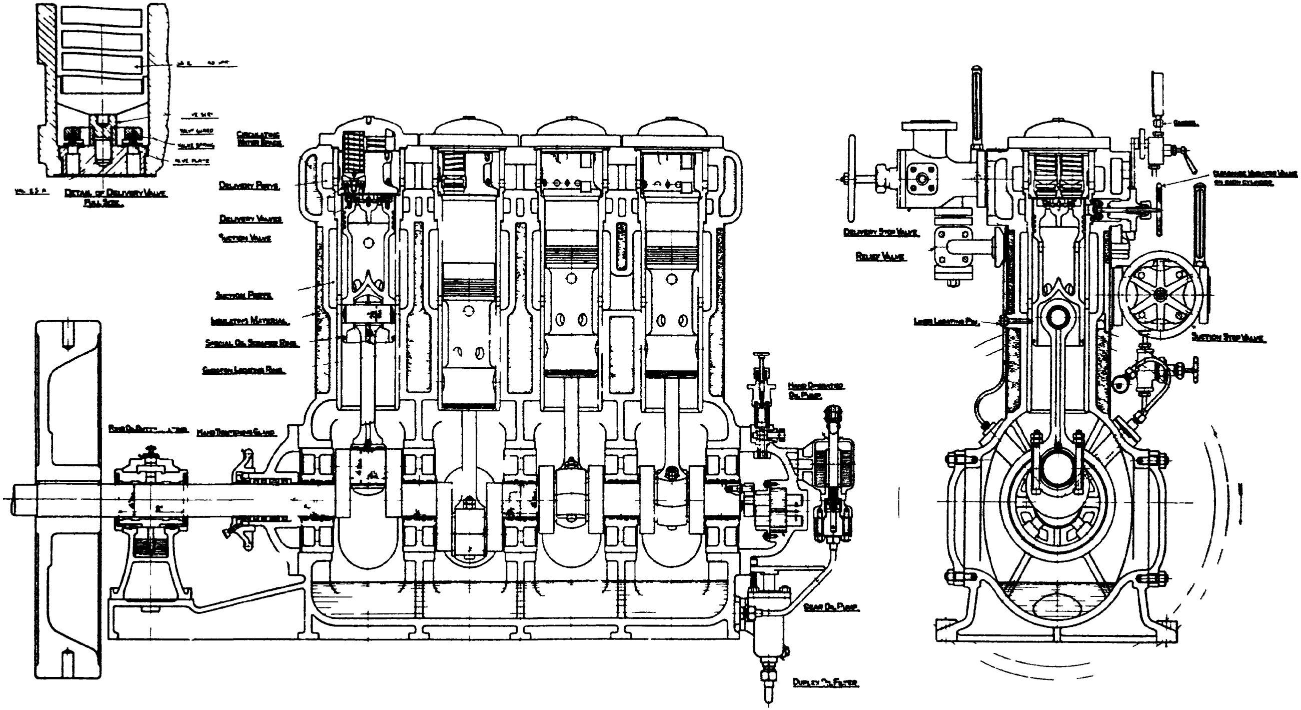

Fig 13 Sectional Arrangement of Four Cylinder Single Acting Ammonia Compressor
(*Peter Brotherhood Ltd*)

Two-stage ammonia compressors are no new things, as they have been constructed for many years as special machines to work in tropical climates. The writing on the wall which foreshadowed their further application was the increasingly low temperatures that are called for both for general cold storage, rapid freezing, and for special applications in the chemical industry and in ice cream freezing.

Another factor is the greater clearance necessary with the high speed, light and completely guarded compressor valves.

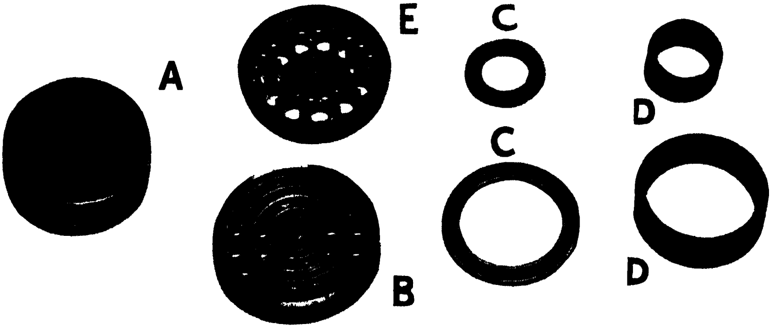

FIG. 14

An increase in clearance means a reduction in capacity which becomes more marked as the ratio of compression increases.

The effects of clearance space in compressors is described in the next chapter. It is sufficient to state here that a small increase in clearance has very little, if any, appreciable effect with the ordinary range of temperatures and pressures for cold storage and ice-making plants when dry compression is used, but for larger total ranges it appears desirable to divide the work of compression into two stages, to reduce the loss of capacity which would otherwise occur.

Some examples of this latest practice are shown in the illustrations that follow.

Machines Built in Great Britain

The Brotherhood Machines.* This firm, who have for over half a century specialized in the manufacture of air and gas compressors, commenced manufacturing refrigerating machinery in 1919, and now produce a large range of ammonia and CO_2 compressors for both land and marine purposes, and for the export market.

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* Messrs. Peter Brotherhood, Ltd., Peterborough.

Fig. 12 is a photograph of the suction side of a four-cylinder single-acting vertical enclosed mono-block compressor of the latest design in which the cross-over and pumping out valves are arranged in the pipe connections.

Fig. 13 is a sectional drawing of the same machine and clearly shows its construction. These machines are made in sizes to give piston displacements at maximum speed of between 180 and 240 cubic feet per minute. The trunk pistons work in centrifugally cast cylinder liners. The suction valve in the top of the piston opens and closes by its own inertia, and the delivery valves in the safety head are provided with very light springs. The cylinder heads are water cooled, and a rotary gear pump gives forced lubrication to all bearings. An external duplex strainer is provided for the lubricating oil, and a hand-pump provides a means of flooding the bearings before the compressor is started up.

These machines can be supplied to work on as many different suction pressures as there are cylinders. The clearance in each cylinder can be controlled by variators shown in section in Fig. 13. The handwheels of these valves—one for each cylinder—are seen in Fig. 12.

Double-acting machines are built up with one, two, or three cylinders, with capacities up to about 150 tons refrigeration per cylinder.

The standard valves used by Messrs. Brotherhood are illustrated in Fig. 14.

Two-stage compressors for use where the temperature required is low, or the temperature of the condensing water is extreme, are coming more and more into use. A two-stage compressor is illustrated in sectional elevation in Fig. 15; it will be noted that the piston rod packings are subject to the suction pressure only.

Fig. 16 illustrates a CO_2 compressor direct coupled to an electric motor. The compressor, valves, and valve blocks

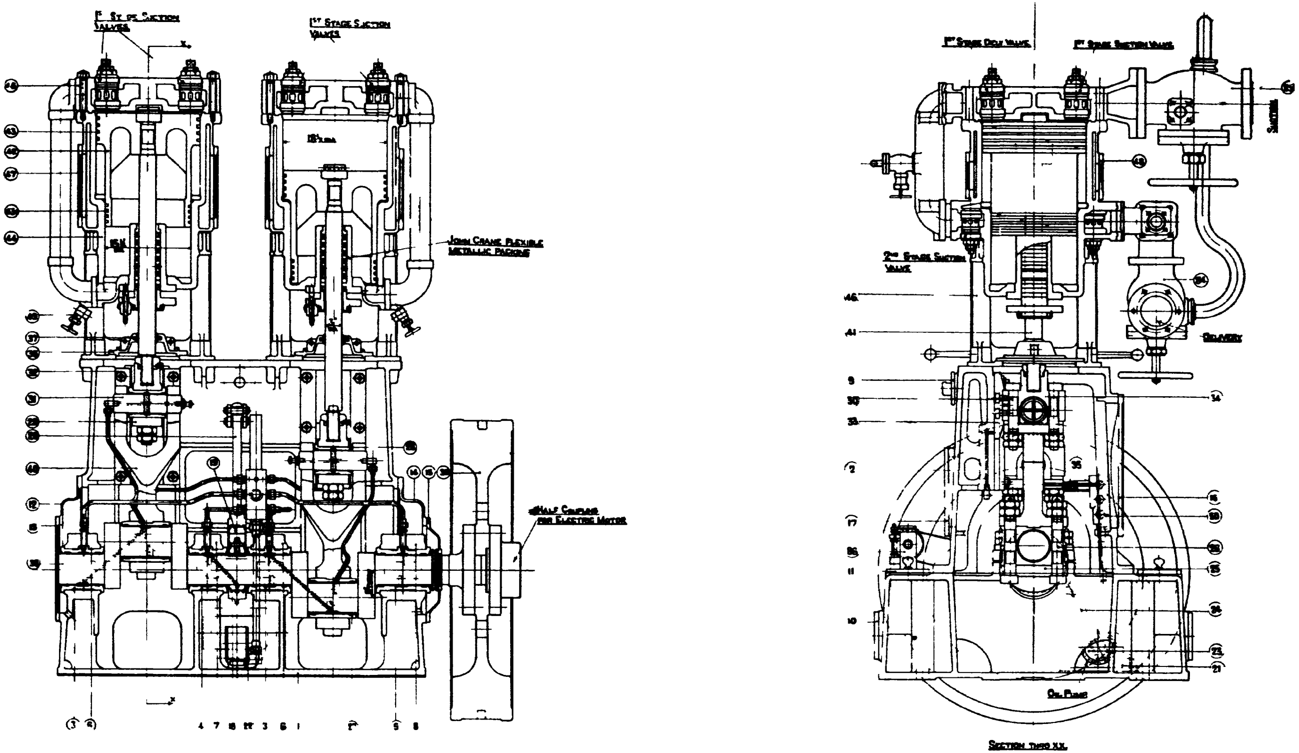

FIG 15 SECTIONAL ARRANGEMENT OF TWO STAGE TWO CRANK AMMONIA COMPRESSOR
(*Peter Brotherhood Ltd*)

are solid steel forgings. Metallic packing is used for the gland.

The Douglas Machines.* For twenty-seven years this firm specialized in the manufacture of vertical single acting and horizontal double acting SO_2 compressors. In 1926 they altered their designs to vertical single acting ammonia compressors. Two ranges of these are made—one medium speed,

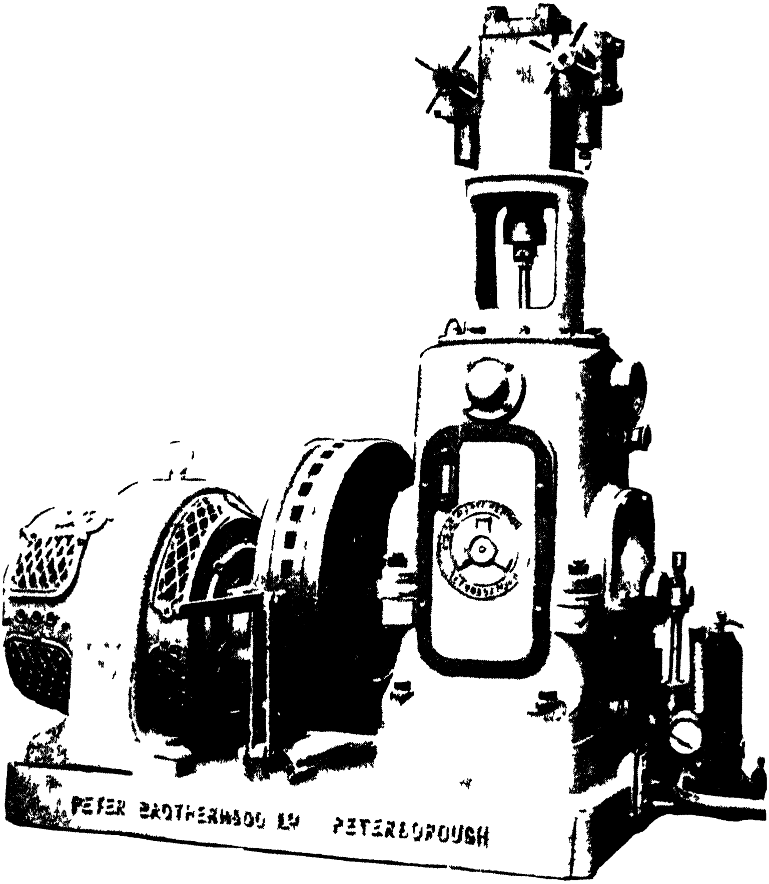

Fig. 16

Messrs William Douglas & Sons, Ltd., Putney, London

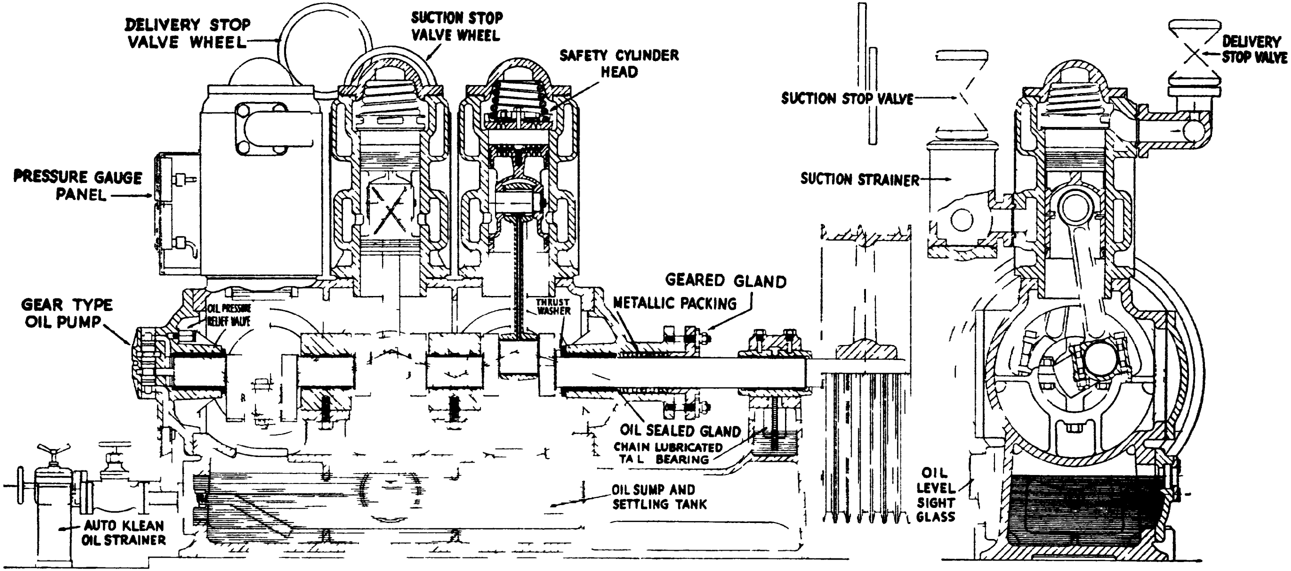

FIG 17 VERTICAL ENCLOSED TYPE SINGLE ACTING TRIPLE NH$_3$ COMPRESSOR
[illegible]

of the return flow type with both valves in the cylinder head; the other running at higher speeds, of the uniflow type, with the suction valve in the piston.

The uniflow machines are made with from two to four cylinders, and run at speeds from 400 to 450 r.p.m. A typical section through a three-cylinder machine is illustrated in Fig. 17. It will be noticed that the cylinders are water jacketed, and that the machine has in all five main bearings. Oil is admitted to the main and big end bearings through wedge-shaped recesses, one on each side of the horizontal centre line of the bearing, i.e. at a point of low bearing pressure. It is considered that the shape of the recesses ensures that an ample oil film is drawn up to the point of maximum pressure; and since two recesses are provided, this effect will occur in whichever direction the compressor is revolving. All bearings are force lubricated by a gear wheel pump, direct coupled to the end of the crankshaft. A hand pump is fitted to flush the bearings before starting up. Flexible metallic packing is used in the main stuffing box, which is adjusted by a geared gland.

The pistons are of the slipper type, and are fitted with scraper rings in the skirts. A safety head, held down by a powerful spring, is fitted to each cylinder, and in it is seated the delivery valve of the Rogler-Hoerbiger type. The suction valves are of the ring plate type, made from tungsten-vanadium steel, and are seated in the piston. Both the suction and delivery valves are accessible without disturbing the pipe connections.

A photograph of an installation, including two twin cylinder machines of this type, is shown in Fig. 18. This particular plant is arranged for fully automatic working.

The Hall Machines.* In 1889 this firm built their first CO_2 refrigerating machine under the patents and to the designs of Windhausen, whose labours in other fields of refrigeration have already been noted, and who invented his first really practical CO_2 machine three years earlier. For many years they confined their attention to this type of machine, and brought it to the high state of perfection it now occupies. Since 1911

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* Messrs. J. & E. Hall, Ltd., Dartford, Kent.

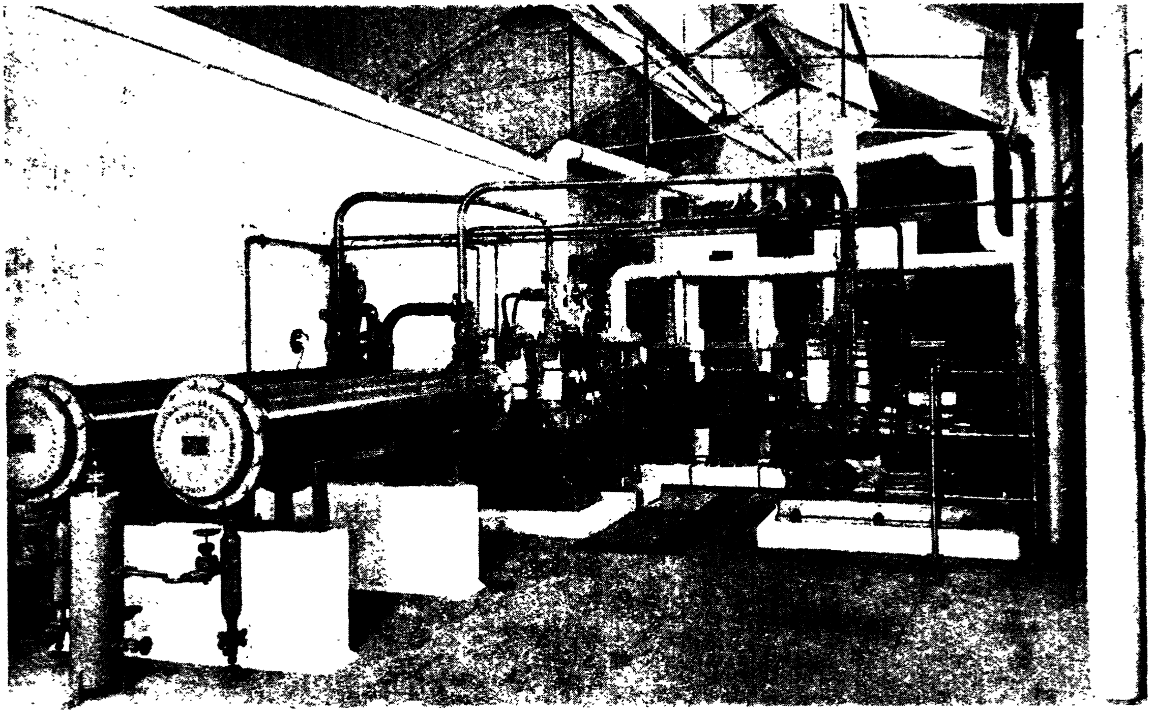


FIG. 18

they have also manufactured ammonia compression machines and more recently have developed the high speed vertical enclosed type which is now their standard pattern for the larger sizes.

They have also developed a range of machines of small size, using methyl chloride as a refrigerant, and known as the "Hallmark." These are made with one to four cylinders, and in single or duplex units, giving a wide range of capacity. They can be supplied with either air cooled or water cooled condensers, though water cooling is only used in exceptional circumstances. They are equipped with completely automatic control. A 1½/2 h.p. triple unit with air cooled condenser is illustrated in Fig. 19. There is a further model using either methyl chloride or Freon as the refrigerant, which, though somewhat similar in design to the Hallmark machines, is outside their range. It has either two or three cylinders 4 in. × 3½ in., and can be completely automatic.

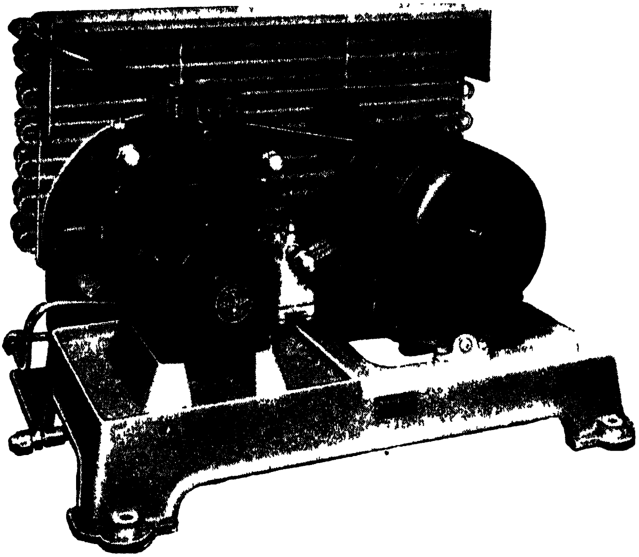


FIG. 19

The almost complete electrification of the modern steamship,

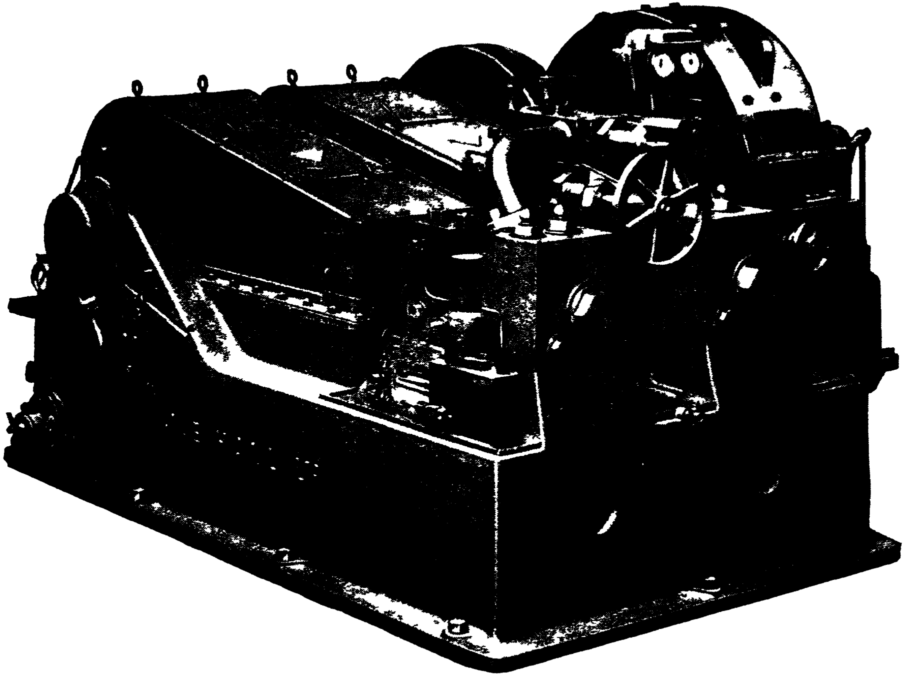


FIG 20

and the introduction of Diesel engines for the main and auxiliary machinery, has produced a demand for CO_2 refrigerating machines of a more compact design than the old tandem steam-driven set which, whatever their advantages may have been, took up a great deal of room. Fig. 20 illustrates a two-cylinder horizontal compressor specially designed for low headroom and direct coupled to an electric motor. The same compressor can also be direct coupled to a horizontal Diesel engine, or to a compound steam engine. These machines have been installed in many ships carrying large cargoes of meat and other produce to this country. The whole of the motion work is mounted on a heavy cast-iron bed, the CO_2 compressor being machined with a sloping face on the upper side, which enables the breeches pipe to the suction valve block to be kept low, thus reducing the height of the machine. The motion work is totally enclosed in oil-tight removable covers with access doors to the crossheads. A baffle plate at the compressor end of the cover forms a separate compartment for the compressor gland, while a small door at the side of the cover gives access to this compartment for gland adjustment when required. Forced lubrication is provided throughout, a hand pump being provided for priming the system before the machine is started up.

Fig. 21 is a section through a CO_2 compressor. It has been machined from a solid forging of high carbon steel of high tensile strength, and takes a high polish in service. The patent metallic gland packing, and the cast-iron piston rings used with these compressors, are also illustrated. A point to note is that these compressors can be used under very much more severe conditions of service than used to be the case when piston and glands were packed with leathers.

Fig. 22 shows a vertical CO_2 machine of the latest design driven by an electric motor coupled directly to its crankshaft, thus ensuring quiet running. These machines are made with one, two, three, or four compressors. The one illustrated is a triple compressor machine. The compressors are of the single-acting type; the motion work is completely enclosed, and there is forced lubrication to all the bearings. The condenser coils for these machines are arranged in separate casings.

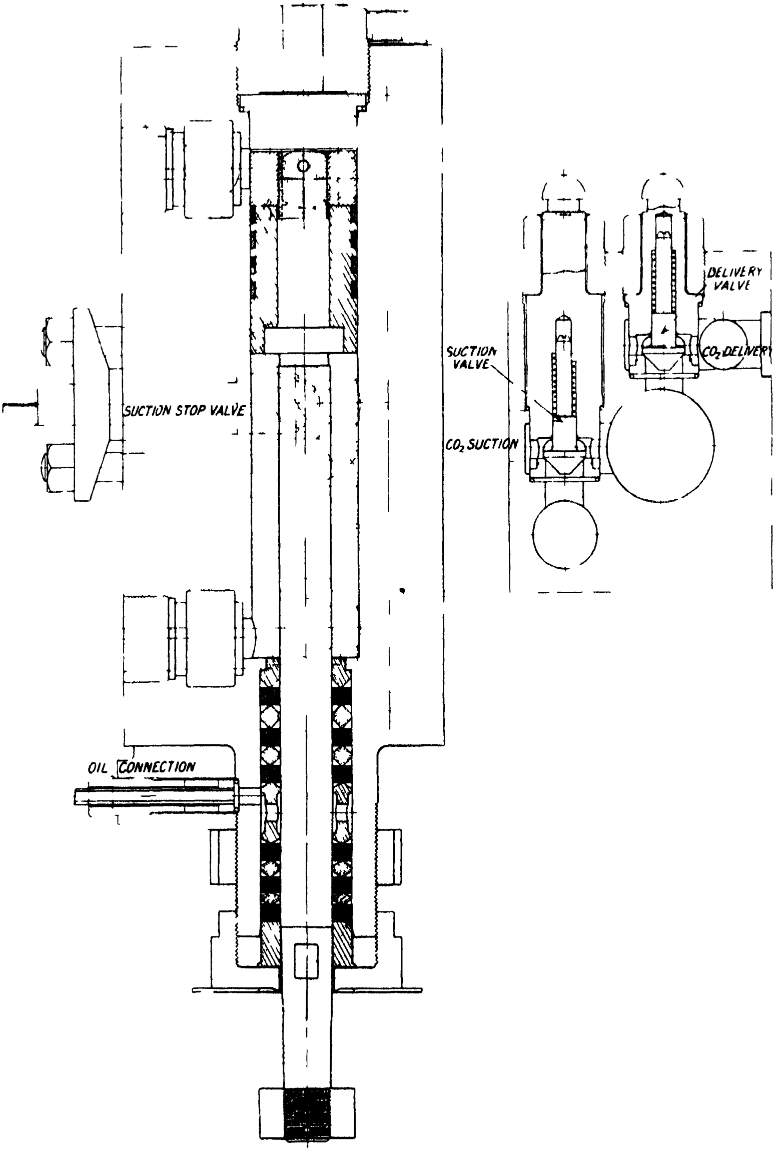

SUCTION STOP VALVE
SUCTION VALVE
CO_2 SUCTION
DELIVERY VALVE
CO_2 DELIVERY
OIL CONNECTION

FIG. 21

Fig. 23 illustrates a four-cylinder single acting vertical enclosed ammonia compressor with an ice-making capacity of 290 tons per day. A half-section and end elevation of this machine are shown in Figs. 24 and 25. The cylinders are bolted to the crankcase, and are fitted with safety heads controlled by helical springs. The suction and delivery valves are of the "ring" type, so arranged that the valves and seats can be withdrawn and replaced without disturbing the pipe connections. The trunk piston is of cast iron with suction port in the centre, and four piston rings at the top and two at the bottom. The connecting rod and the crankshaft are of forged steel, machined all over. The crankshaft is carried in five

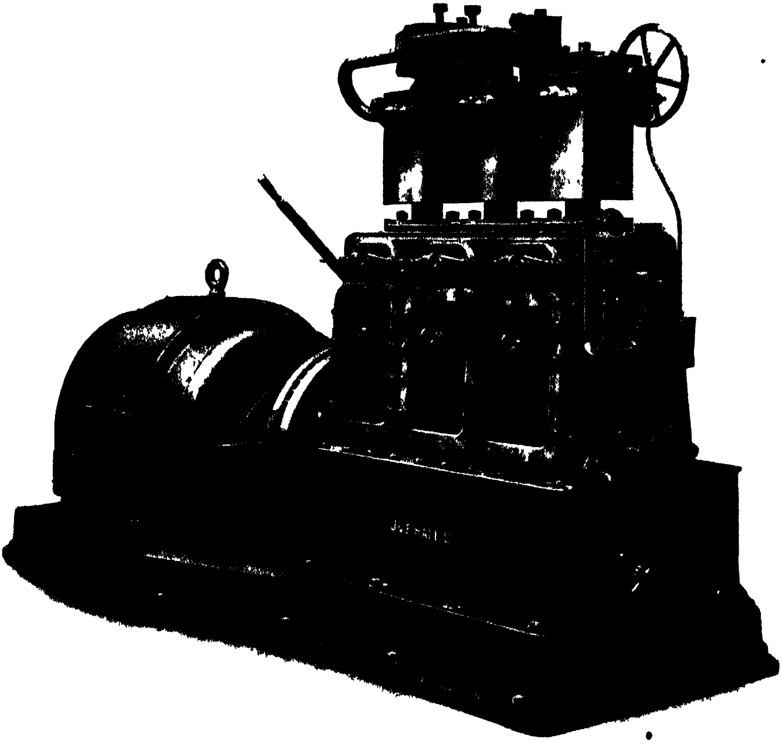


Fig. 22

main bearings lined with white metal, and passes through a stuffing box fitted with metallic packing. The crankcase is fitted with large inspection doors on each side, and an oil sight glass to indicate the oil level. Forced lubrication is applied to all moving parts from a plunger oil pump driven directly off the crankshaft. The forced lubrication system is external to the crankcase and includes oil filters in duplicate.

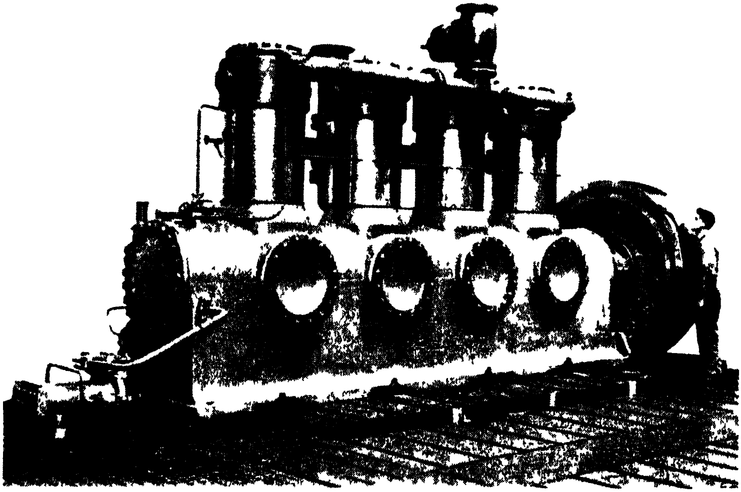
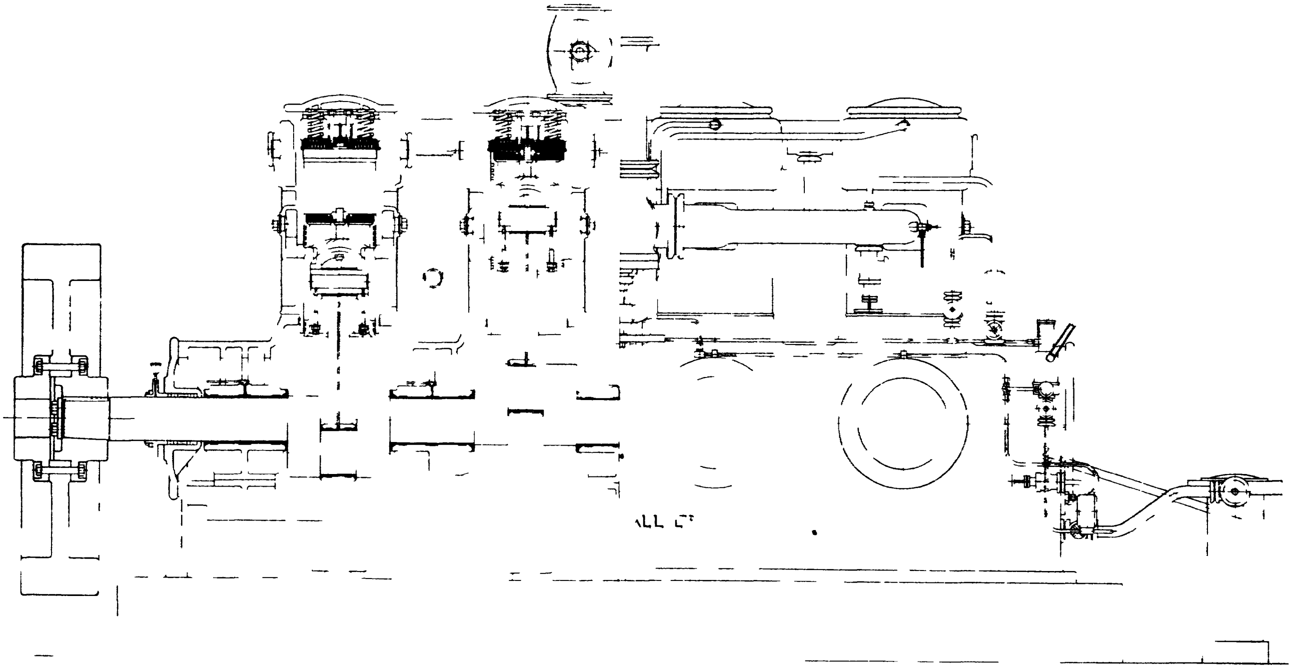


FIG. 23

The header pipes are mounted on the compressor and are fitted with suction and delivery screw-down stop valves, by-pass valve, and special by-passing safety disc and crossover pump-out connections. A strainer is fitted on the suction side, and an oil separator with drain valve on the delivery. The valve wheels are interlocking, so that the suction valve cannot be opened before the delivery valve. The compressor is designed to run at speeds up to 250 r.p.m., and is suitable for direct coupling to an electric motor or other prime mover. This type of compressor is built in a large range of sizes, having two, three, and four cylinders; the speed varies according to the size. and runs up to 600 r.p.m. in the smaller units. The three



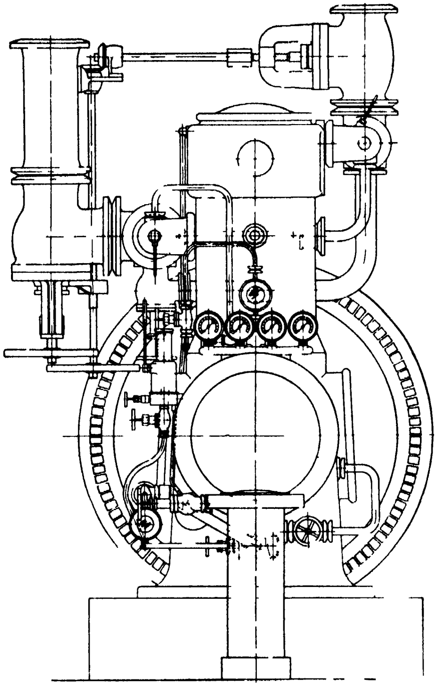
(*J & E Hall, Ltd*)

FIG. 24 ARRANGEMENT OF $16\frac{1}{2}$ IN BORE 15 IN STROKE, VERTICAL ENCLOSED TYPE HIGH-SPEED AMMONIA COMPRESSOR

Part sectional Front Elevation

and four cylinder compressors are often arranged to work on the compound compression system.

The design of the smaller size high-speed single-acting enclosed machine is illustrated in Fig. 26. The cylinders are water jacketed and are fitted with a safety head controlled by a helical spring. The whole of the motion work is automatically lubricated and enclosed within the crankcase, which is fitted with a large inspection door. The gland is of the rotary type fitted with metallic packing. The compressor is fitted with suction strainer, suction and delivery stop valves, oil separator with oil sight glass and drain valve, and an oil pump for adding oil to the crankcase while the machine is running. It is arranged for belt drive or for direct coupling to an electric motor, both being mounted on a substantial cast-iron bedplate.



(*J & E Hall, Ltd.*)

Fig. 25 Arrangement of 16½ in. Bore, 15 in Stroke, Vertical Enclosed Type High-speed Ammonia Compressor

In 1940 Messrs. J. & E. Hall acquired the goodwill of the refrigerating business of the Liverpool Refrigerating Co., Ltd., which had previously absorbed Messrs. H. J. West & Co., whose sleeve-valve machines, invented by the late Mr. E. Prestage, were described and illustrated in previous editions of this book, under the heading of "The West Machines." These sleeve valve machines are not now one of Messrs. J. & E.

Hall's standard models, but as they are still manufacturing them and they undoubtedly fill a want, a repetition of the technical description will be helpful.

These machines employ the single-sleeve type of valve, in which the reciprocating sleeve itself forms the working cylinder barrel, the drive for the sleeve being obtained from eccentrics formed on the crank webs. In the smaller sizes, the suction and delivery valve ports are formed in the sleeve. and although it is impossible to arrange the timing of the valve to suit all conditions of working, it is claimed that the loss of efficiency is more apparent than real, and is more than counterbalanced by the simplicity of the arrangement and entire absence of the ordinary valves.

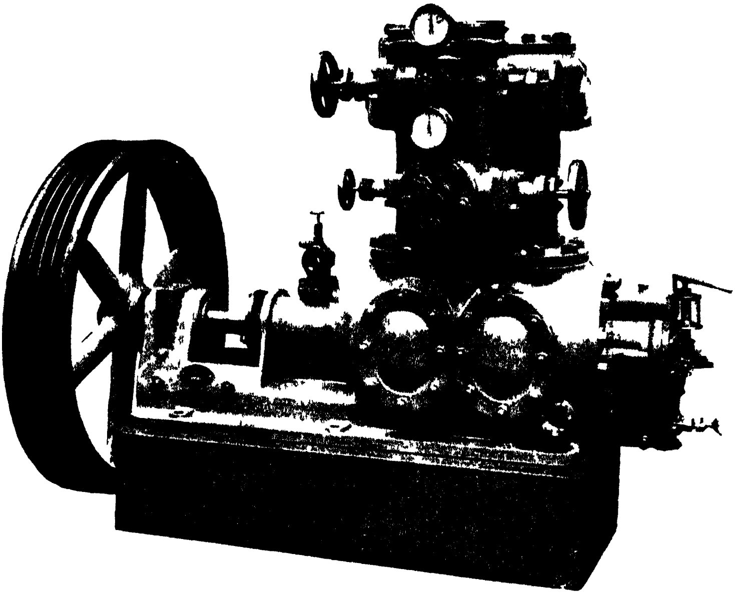


Fig. 26

In the larger machines, the sleeve valve only operates on the suction ports, and light automatic delivery valves are provided in the cylinder head while, by having two sets of suction ports, it is possible to use one compressor to work on two separate

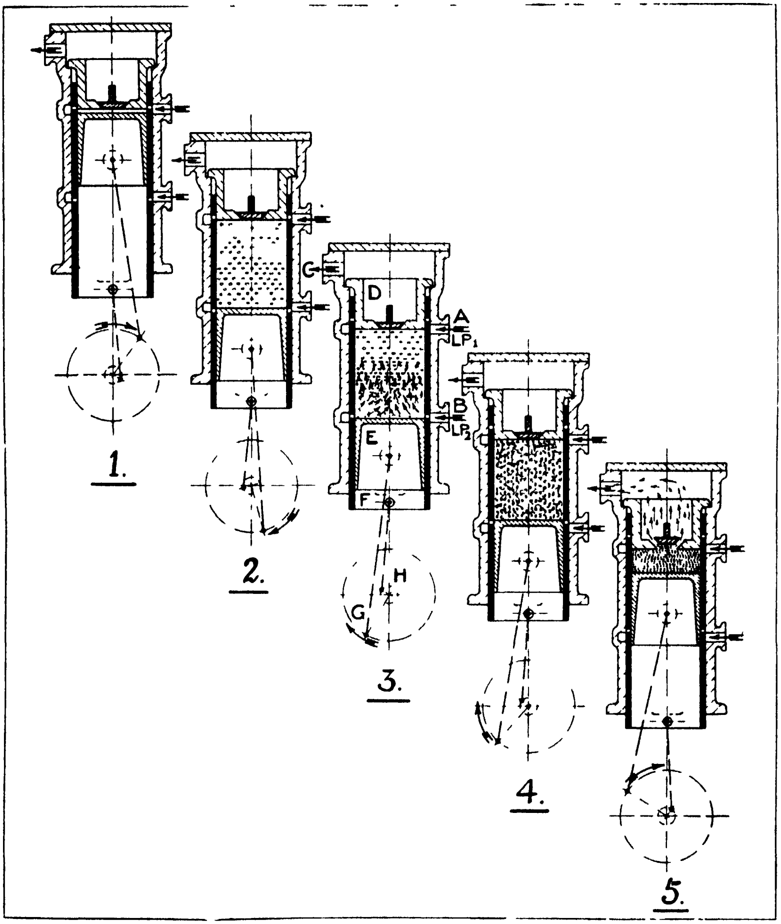


FIG. 27.—DIAGRAMS SHOWING THE FUNCTIONING OF THE DOUBLE SUCTION-PORTED SLEEVE-VALVE COMPRESSOR

A. Suction (LP_1).
B. Suction (LP_2).
C. Discharge.
D Safety head.
E. Piston.
F. Ported sleeve.
G. Crank path.
H. Eccentric travel.

suction pressures in each cylinder. Fig. 27 illustrates the relative positions of the piston and of the valve through one revolution. At 1 the upper ports are opening, and when there are two suction pressures, the gas at the lower pressure enters through these; at 2 the piston is nearly at the bottom of its stroke, the top suction ports have just closed, and the lower ports are about to open, and suction gas at a higher pressure can enter as shown in 3. At 4 both sets of ports are closed, and on the up-stroke of the piston the compressed gas is discharged through the delivery valve in the cylinder head, as at 5.

Fig. 28 illustrates a three cylinder compressor. The machine is of the single acting vertical enclosed type with the gland on the crank shaft. Forced lubrication is used, and with both patterns of sleeve valve the safety head feature is employed.

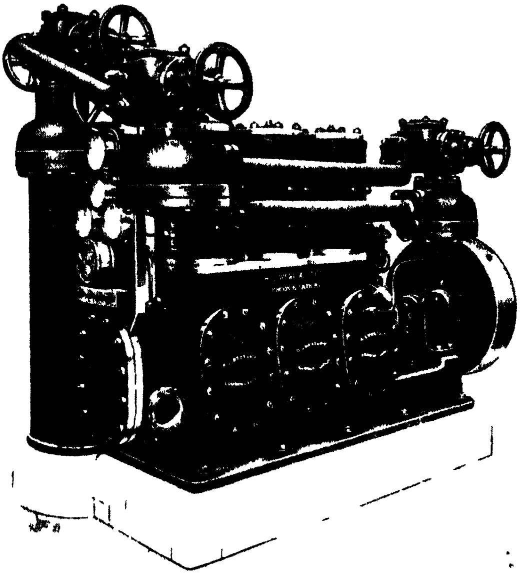


Fig. 28.—The West Machine

The particular machine shown is built for coupling to a direct current electric motor, having a speed variation of 440 to 750 r.p.m.; push-button control is provided, and this, with the ammeter, is mounted on the gauge board, so that the engineer, by standing at the end of the machine, has everything to hand.

Fig. 29 illustrates an installation comprising three twin-cylinder sleeve valve ammonia compressors, each arranged to

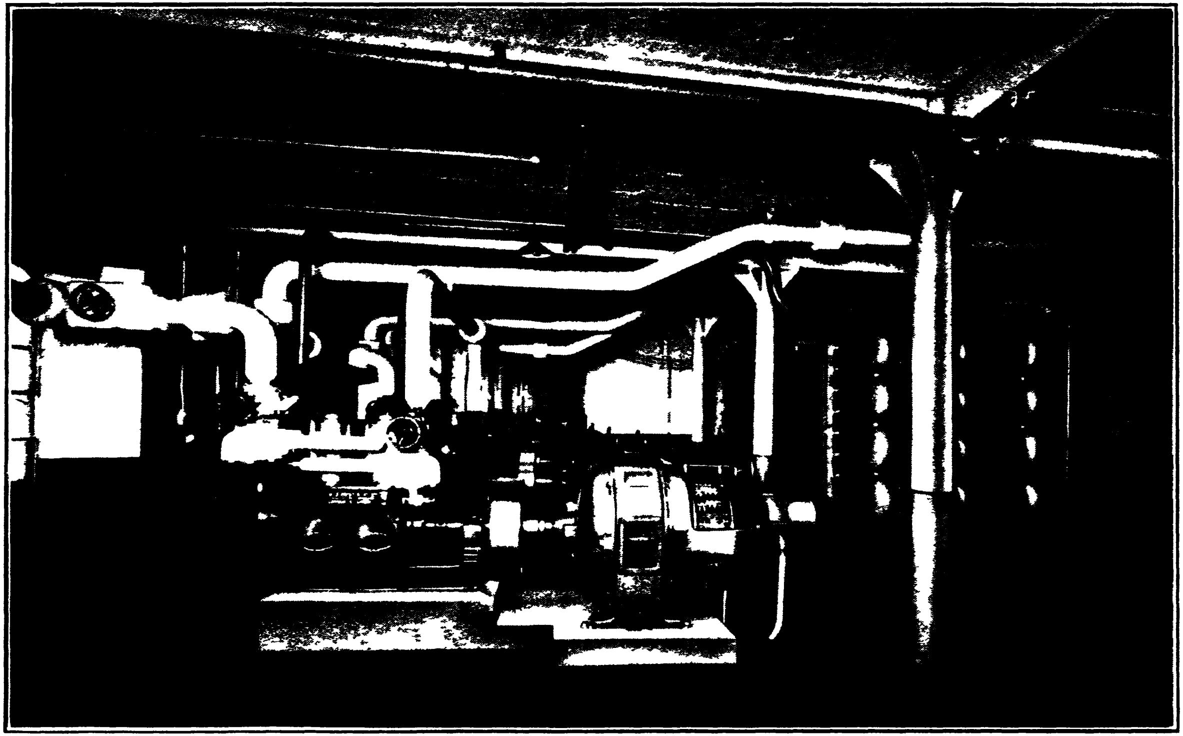


FIG. 29

work with two suction pressures in each cylinder, and direct coupled to a three-phase A.C. 50 cycle motor, which may be run at speeds varying by fine graduations from 183 r.p.m. to 550 r.p.m.

By variation of the speed and of the supercharge through the lower suction parts the capacity of this installation can be varied from 18 to 250 tons refrigeration, a range of about 1,400 per cent. Regulation of the refrigerating plant when the load is varied is also very frequently effected by regulating the speed of the compressors instead of by adjusting the regulating valves.

The illustration also shows the multi-tubular counter-current ammonia condensers.

The Lightfoot Machines.* The Lightfoot Refrigeration Co., Ltd., build ammonia, methyl chloride, and Freon refrigeration machines.

Fig. 30 illustrates a four-cylinder high-speed vertical enclosed type ammonia compressor direct coupled to an electric motor and in Fig. 31 is shown the part section of a similar three-cylinder machine.

The suction and delivery valves are of the light disc pattern, the suction valves being accommodated in the top of the piston. The design also provides a spring-loaded safety head. An enclosed oil pump driven from the end of the crankshaft provides forced lubrication to all bearings except the outer bearing which is ring lubricated. Two external oil filters are supplied, permitting one to be cleaned whilst the compressor is in operation. A hand-operated pump is provided for adding oil to the crankcase when required and to enable the pipe connections and bearings to be primed with oil before the compressor is started up. The main crankshaft gland is of the metal faced type in communication with the forced lubrication system. This gland remains tight without requiring any adjustment.

Fig. 32 illustrates the horizontal high-speed double acting compressor. The frame is designed to take thrust on the centre line of the cylinder and the bored guide for the crosshead

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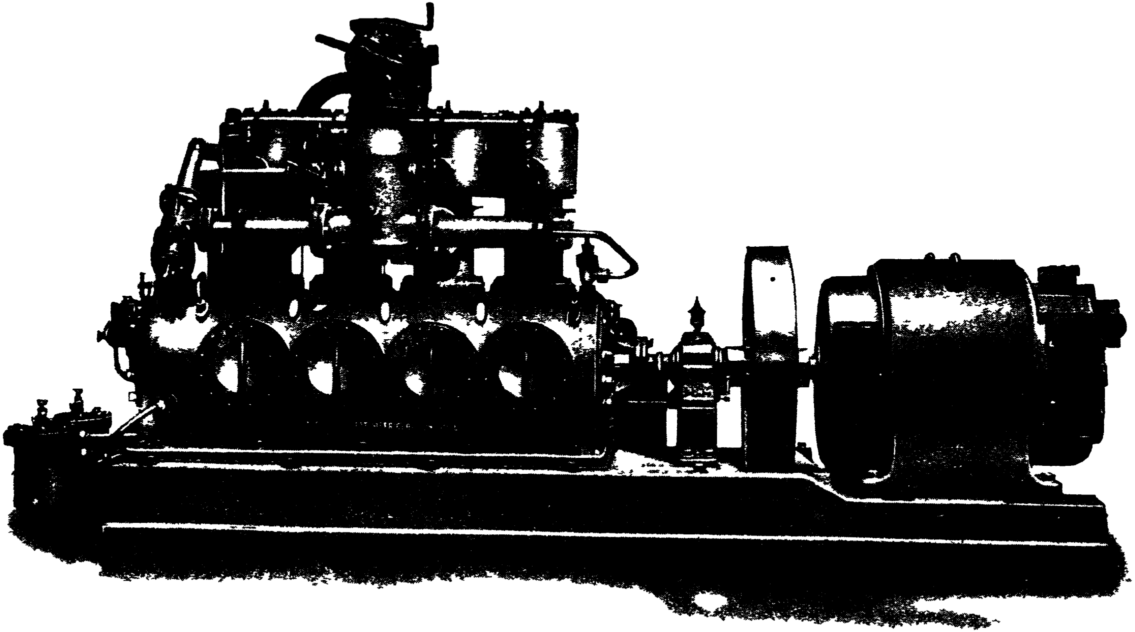
* The Lightfoot Refrigeration Co., Ltd., London.



(The Lightfoot Refrigeration Co., Ltd)

FIG 30

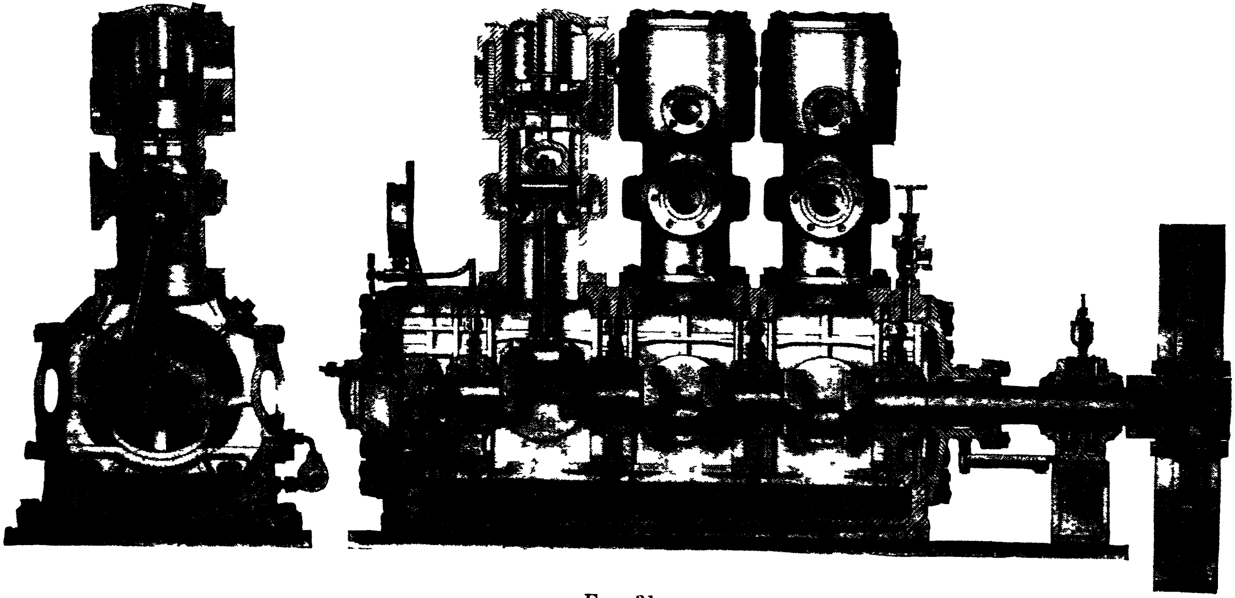


FIG. 31

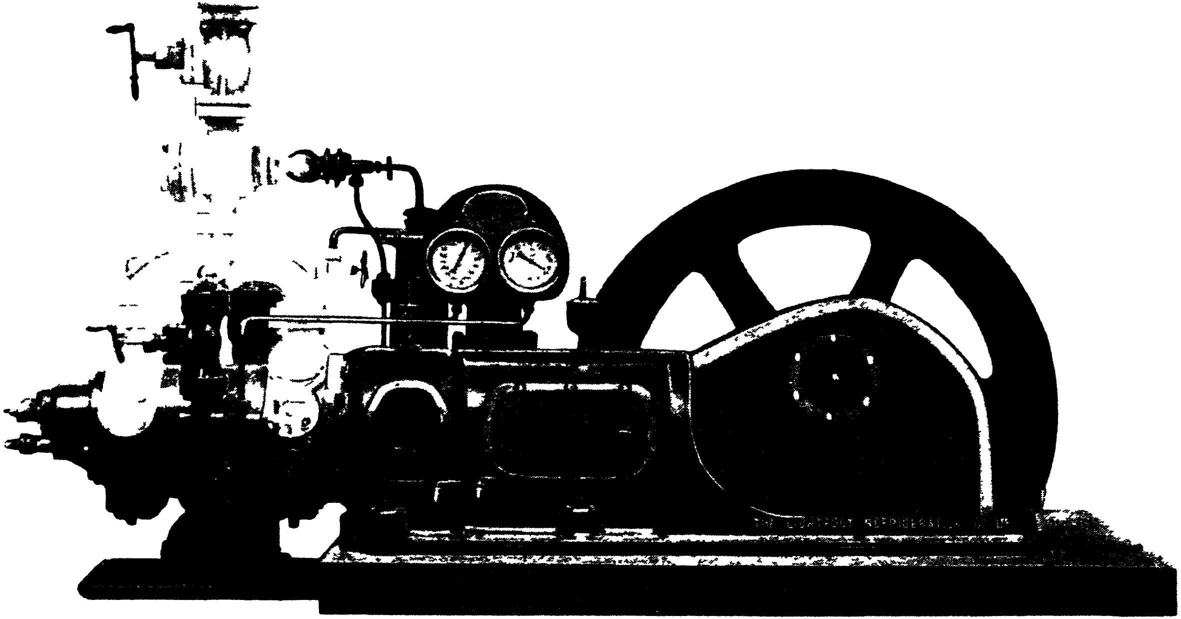
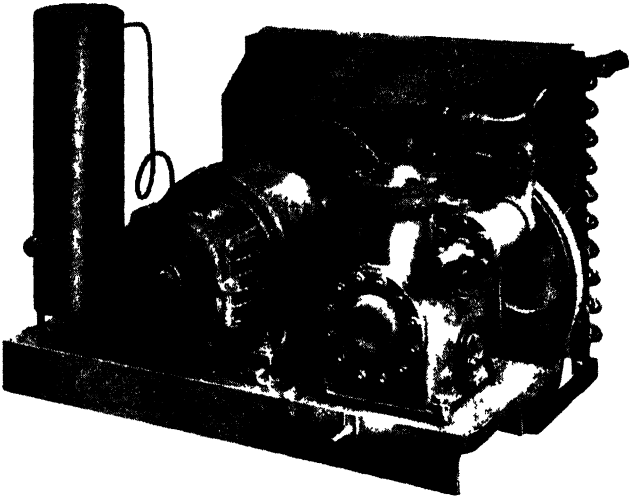


FIG. 32

is cast with and forms part of the main frame and bedplate. The crankshaft is balanced. The light disc suction and delivery valves are arranged circumferentially round the cylinder and can be removed without disturbing any connections. Forced lubrication is provided for all bearings, the moving parts being enclosed by easily removable planished steel covers.

These machines are designed to run at from 180 to 275 r.p.m.,



(The Lightfoot Refrigeration Co Ltd)

FIG. 33

depending on the size, and are made in capacities up to 150 tons ice-making output per cylinder. The design lends itself to direct coupling to an oil engine or to a high economy steam engine of the drop valve or uniflow type and for direct coupling to motors mounted direct on the crankshaft.

Fig. 33 shows a typical methyl chloride or Freon compressor and air-cooled condenser assembly with forced air draught for the condenser. The plant is designed for automatic operation and the compressor has a special metal face to face bellows gland. Particular attention being given to silent running. Thermostatic regulator valves are fitted and the plant is

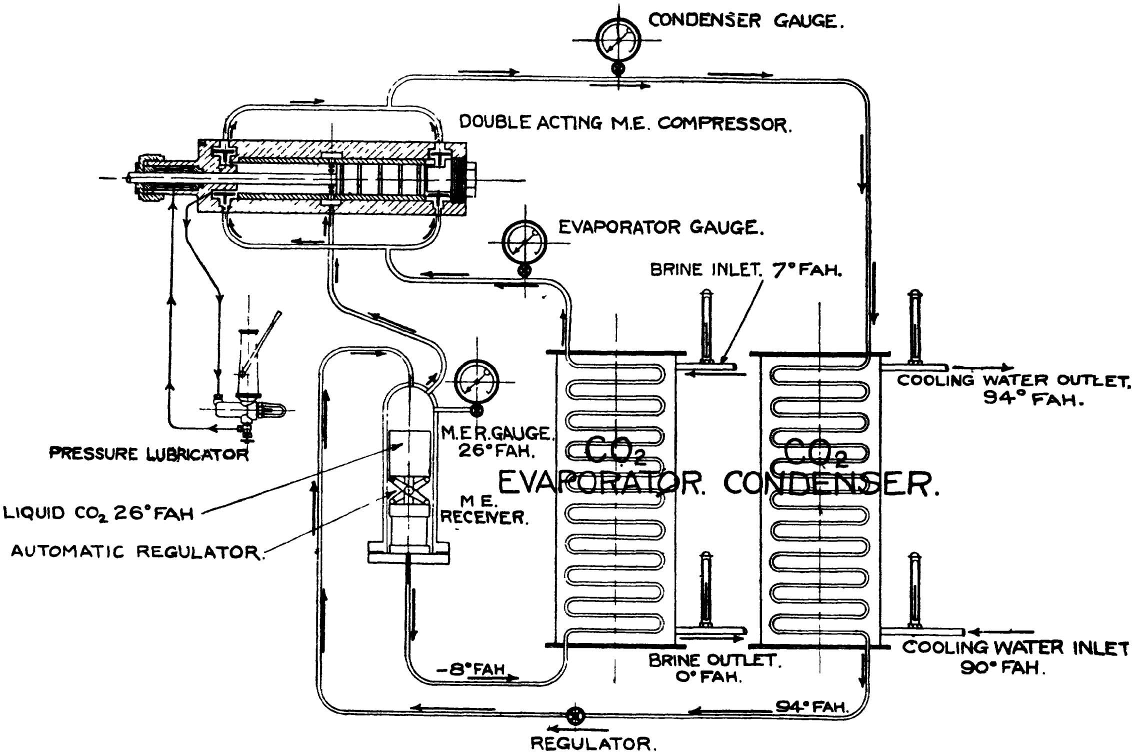
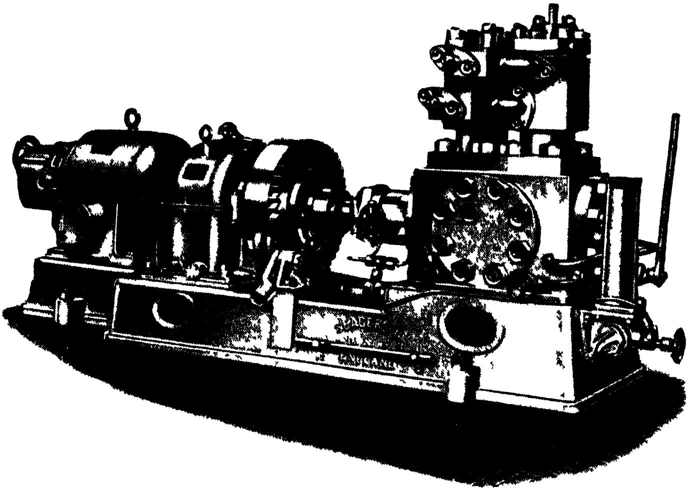

CONDENSER GAUGE.
DOUBLE ACTING M.E. COMPRESSOR.
EVAPORATOR GAUGE.
BRINE INLET. 7° FAH.
COOLING WATER OUTLET. 94° FAH.
PRESSURE LUBRICATOR
M.E.R. GAUGE. 26° FAH.
CO_2 EVAPORATOR.
CO_2 CONDENSER.
LIQUID CO_2 26° FAH
M.E. RECEIVER.
AUTOMATIC REGULATOR.
-8° FAH
BRINE OUTLET. 0° FAH.
COOLING WATER INLET 90° FAH.
94° FAH.
REGULATOR.

Fig. 34

complete with high pressure overload. Water-cooled condensers are also supplied, and the range of sizes varies from $\frac{1}{4}$ to 15 horse-power. The low pressure side is supplied in a variety of forms to suit the particular duty.

The Seager Machines.* Messrs. Seager, Ltd., specialize in supercharged multiple effect compression machines, which are arranged for pre-cooling by primary evaporation with automatic regulation. This arrangement, it is claimed, greatly enhances their refrigerating value under all temperature conditions for both marine and land service.



(*Seagers, Ltd.*)

FIG. 35

The cycle is shown in Fig. 34.

The refrigerant, in its passage from the condenser to the evaporator, is pre-cooled by expansion through a regulator valve into a primary evaporator vessel, where the liquid portion separates from the vapour; it is then further expanded through an automatically controlled regulator valve to the evaporator at the desired pressure and temperature. This ensures that nothing but liquid refrigerant at a very low temperature enters the evaporator. The vapour, which has been separated from the liquid in the receiver, enters the compressor through ports which are uncovered at the end of each stroke, thereby supercharging the compressor, improving its volumetric efficiency, and greatly increasing the heat transfer to the condenser.

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* Messrs. Seagers, Ltd., Dartford, Kent.

Where the temperature of sea circulating water varies between the extremes found in this country and in the tropics, it is claimed that the introduction of this cycle gave a gain of 128 per cent in refrigeration, or, alternatively, a saving of $47\frac{1}{2}$ per cent power for the same output.

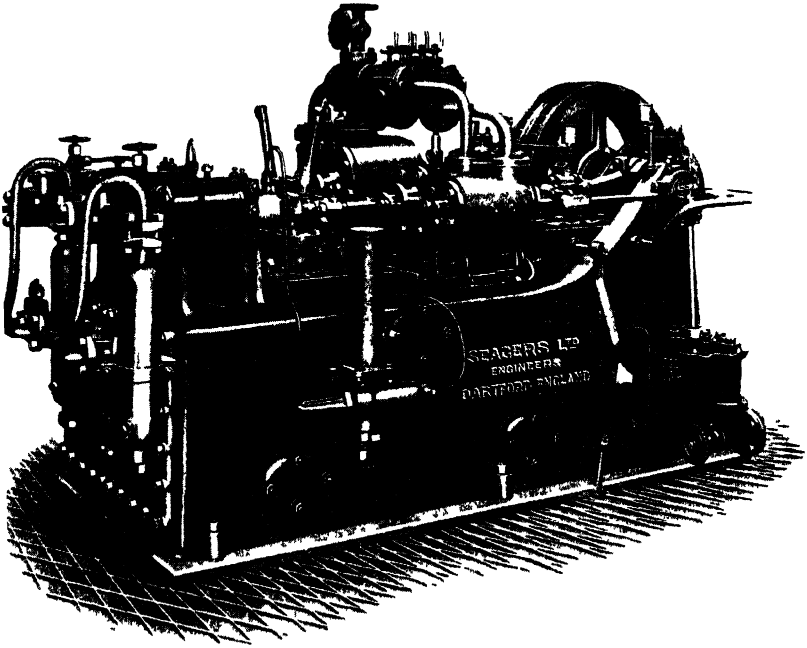

Fig.

A totally-enclosed twin steel CO_2 machine is shown in Fig. 35, arranged for geared or direct electric drive and running at 300 r.p.m., incorporating pre-cooling and multiple effect compression. Every wearing part is renewable, and cylinder liners, valve seats, valves, crank and gudgeon bearings are hardened to between 650 and 700 Brinell.

A duplex marine type machine, driven by a cross-compound steam engine, is shown in Fig. 36.

The Sterne Machines.* This firm specializes in the manufacture of ammonia compressors of the single acting, vertical enclosed, high-speed type, in all sizes ranging up to 200 tons ice-making capacity. The larger sizes are usually arranged for direct coupling to the prime mover, but the smaller sizes are now more usually arranged for vee-drive belt, but can be direct coupled when desired. A range of standard cylinder sizes is made, and machines are built with two, three, or four cylinders to give intermediate capacities. Speeds range from 750 r.p.m. for the small machines to 250 or 300 r.p.m. for the large sizes.

The general design will be seen from Fig. 37, which shows a section through a three-cylinder machine. The suction valves are arranged in the piston, and the discharge valves in the spring-loaded safety cylinder head. Both suction and discharge valves are of the light ring plate type in units complete with their seats which can readily be renewed. The cylinders have water jackets around the upper part. Forced lubrication is fitted, and the rotary crankshaft gland is sealed with oil under pressure. The latest machines are fitted with an "Auto-Klean" oil strainer which can be cleaned without opening up.

Fig. 38 shows a medium sized compressor direct coupled to its driving motor. This machine is fitted with variable clearance cylinder heads, a device which makes possible the adjustment of the capacity developed by the machine whilst running at constant speed.

For use where low temperatures and suction pressures and high condenser pressures necessitate working with a large ratio of compression a range of vertical enclosed, two-stage compressors is made in which the high-pressure and low-pressure cylinders are arranged in tandem. The piston is of the stepped type, the low-pressure cylinder being formed by the annular space between the large and small diameter parts, and the high-pressure cylinder by the space above the small diameter part. As has already been pointed out, these two-stage compressors result in a very considerable increase in efficiency and

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* Messrs. L. Sterne & Co., Ltd., Crown Ironworks, Glasgow.

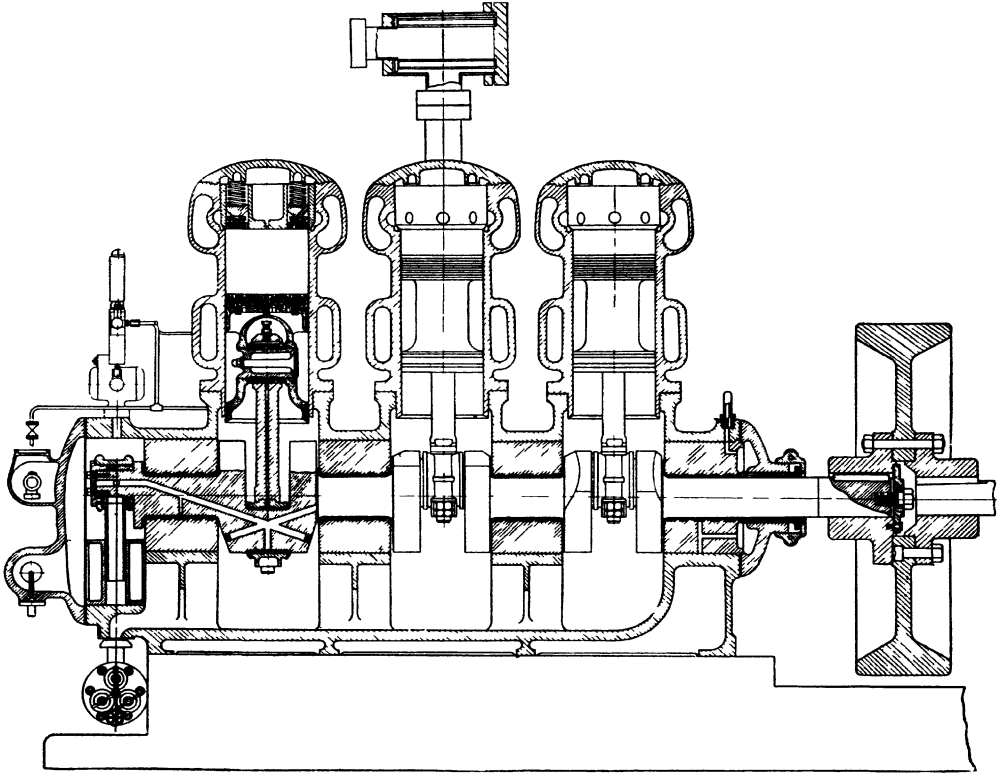


FIG 37

reduction in power consumption as compared with the ordinary single-stage machine where low suction pressures are required for low temperature refrigeration work, particularly where high condenser pressures also occur.

Fig. 39 illustrates a four-crank, two-stage compressor of this type complete with intercooler which cools the gas between stages by injection of liquid ammonia.

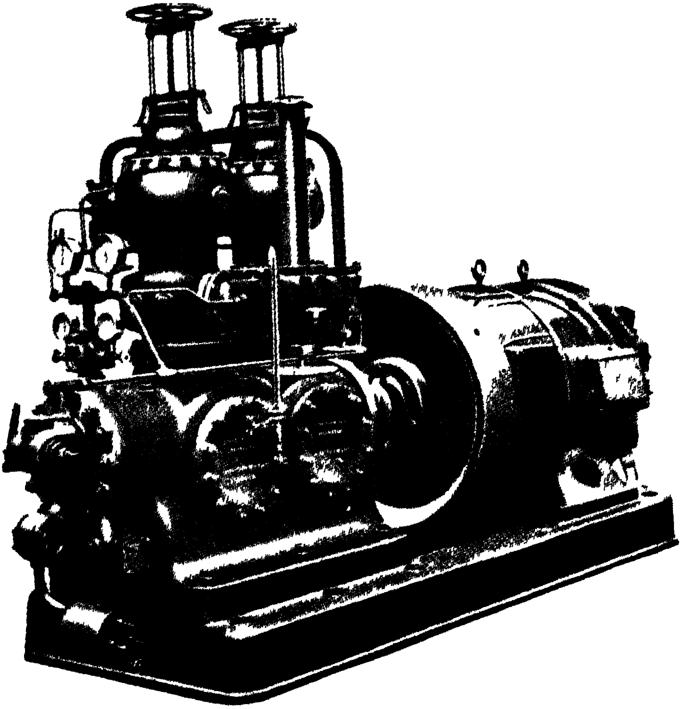


FIG. 38

For use with the modern refrigerants, Freon and methyl chloride, the standard range of ammonia compressors is fitted with cylinders of larger diameter and certain other special features. For smaller capacities, however, a standard range of machines is made suitable for Freon or methyl chloride in sizes from $\frac{1}{4}$ to 15 h.p. These machines are usually assembled complete with driving motor and condenser to form a self-contained unit. Up to 2 or 3 h.p. size the condenser may be air-cooled, consisting of a radiator carried on the bedplate. Air is blown over the condenser coils by a fan mounted on the motor shaft.

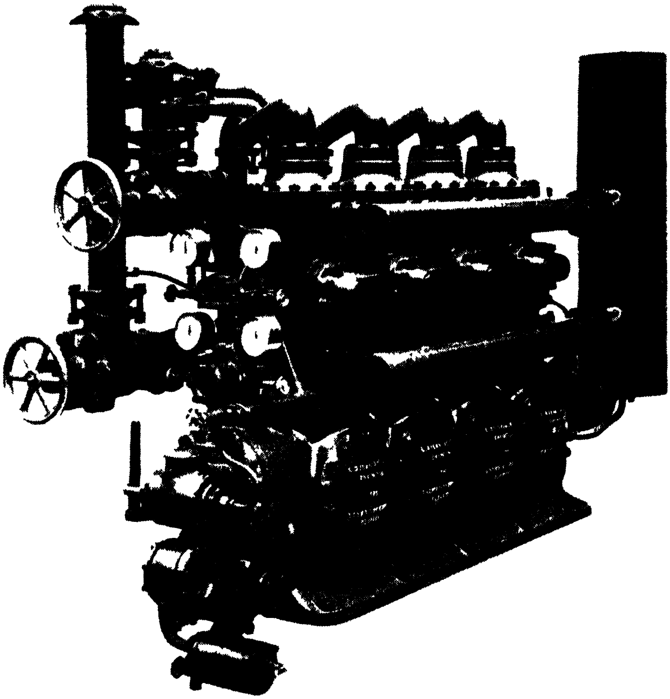


Fig 39

Fig. 40 shows a typical unit of this type with water-cooled condenser. These units are designed primarily for automatic control. Except in the smallest size, they have either two or three cylinders. Lubrication is on the splash system, and a bellows type crankshaft gland seal is employed.

In 1938, Messrs. L. Sterne & Co. acquired the business of The Haslam Foundry & Engineering Co., Ltd., and, except in special cases. the Haslam design of ammonia compressor is no longer made. They continue, however, to manufacture the Haslam CO_2 compressor. These are now usually of the vertical enclosed, single acting type. The illustration, Fig. 41, shows a large three-cylinder machine, which is arranged for direct coupling to an electric motor for use on board ship. Horizontal machines are also made, where headroom is lacking. The compressors are single acting so that the piston rod gland is subjected only to the suction pressure. The cylinders are fitted with cast-iron liners and are usually arranged for working on the liquid pre-cooling cycle with multiple effect compression.

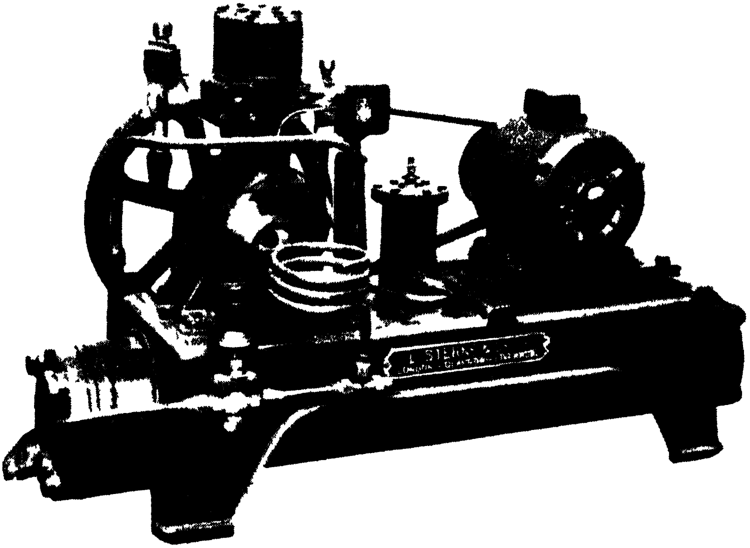


FIG. 40

The cycle is illustrated in the diagram, Fig. 42, which is self-explanatory. It is designed to ensure the almost complete liquefaction of the gas before it passes to the evaporator, and very large economies, both in increased output and in saving in horse-power, are claimed. In practice the compressor is single acting, and the pre-cooler controlled by float.

The cold air machine which was introduced by Messrs. Haslam in 1878, and by means of which some of the earliest

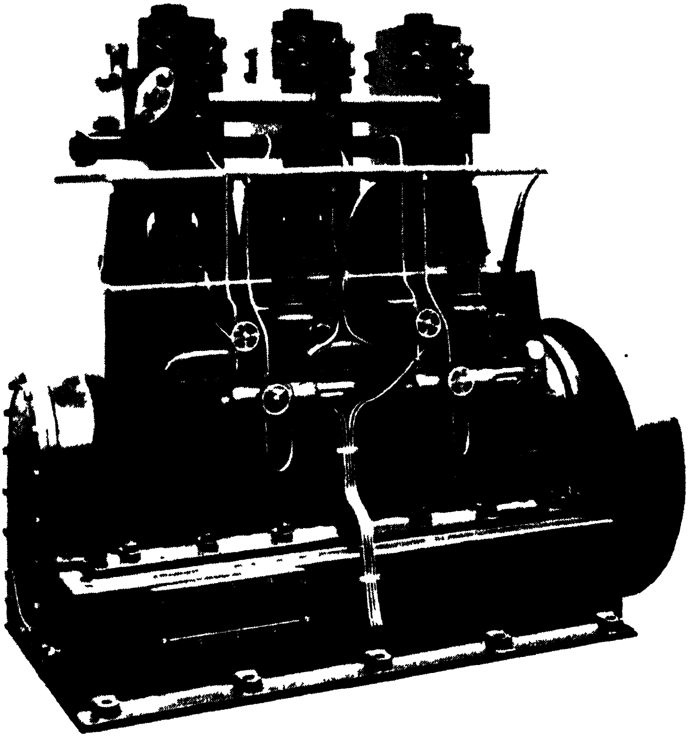
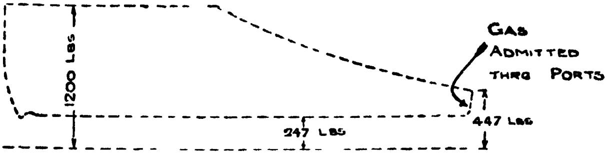


Fig 41

shipments of frozen meat were carried to this country, is still made for special purposes. With modern improvements it finds a use in the production of specially low temperatures for certain purposes. With this machine, temperatures as low as — 140° F. can be obtained. Fig. 43 shows a modern cold air machine arranged for vee-rope drive. The compressor and expansion cylinders are mounted side by side on the crankcase, all motion



Indicator Diagram

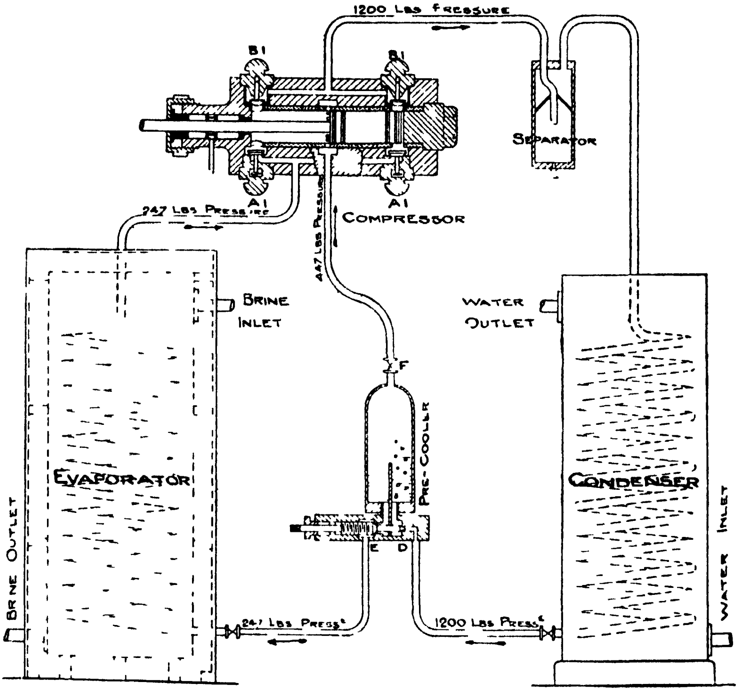


Fig. 42

work being enclosed and fitted with forced lubrication. A mechanical lubricator is fitted for feeding oil to the expansion cylinder and valves.

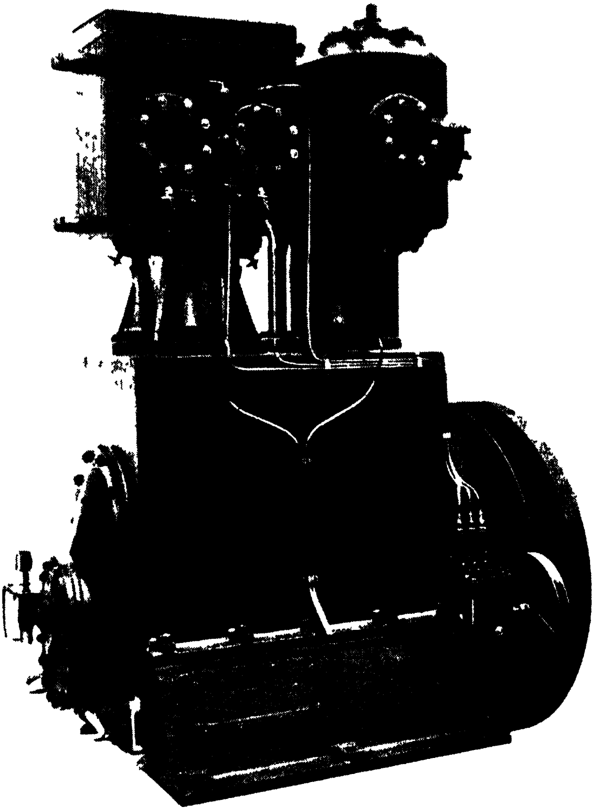


FIG. 43

The U.D. Machines.* The U.D. Engineering Co., Ltd., as manufacturers of refrigerating apparatus, to-day build compressors of the modern vertical enclosed type suitable for operation on ammonia, CO_2, or Freon.

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* The U.D. Engineering Co., Ltd., Park Royal, London.

The range of ammonia compressors is extensive with operational speeds from 450 r.p.m. on the larger sizes and 700 r.p.m. on the smaller sizes. The machines are thus suitable for direct coupling to the prime mover or for driving by vee-ropes as may be preferred. Fig. 44 illustrates one of their four-cylinder totally enclosed high-speed vertical single acting machines, while Fig. 45 is a sectional elevation of the same machine. It will be noted that the cylinders are water jacketed and that they are cast separately, and that the crankshaft is supported on bearings between each cylinder.

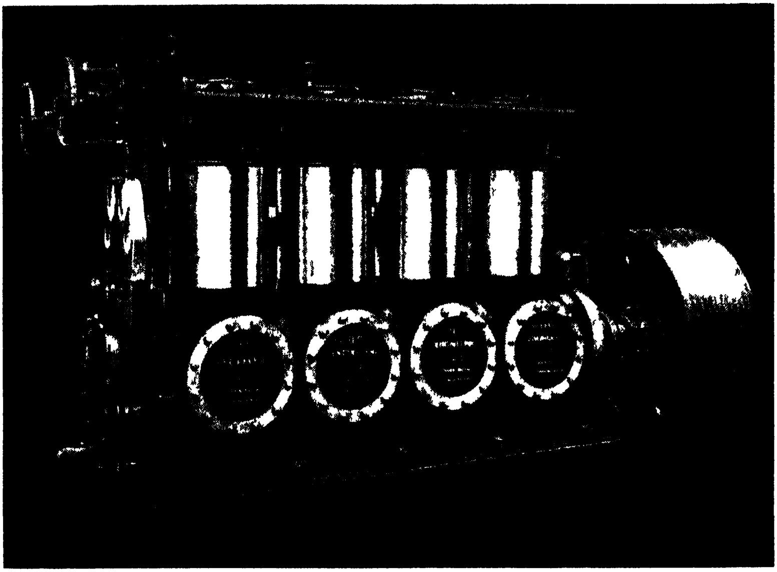

FIG 44

The suction and delivery valves, which are interchangeable, are of the ring plate type, the suction valves being mounted in the piston and the delivery valves in the spring loaded safety head plate. The gas flow through the cylinders is thus of the uniflow form, while the whole of the valve gear can be withdrawn and replaced without disturbing the motion work or pipe connections.

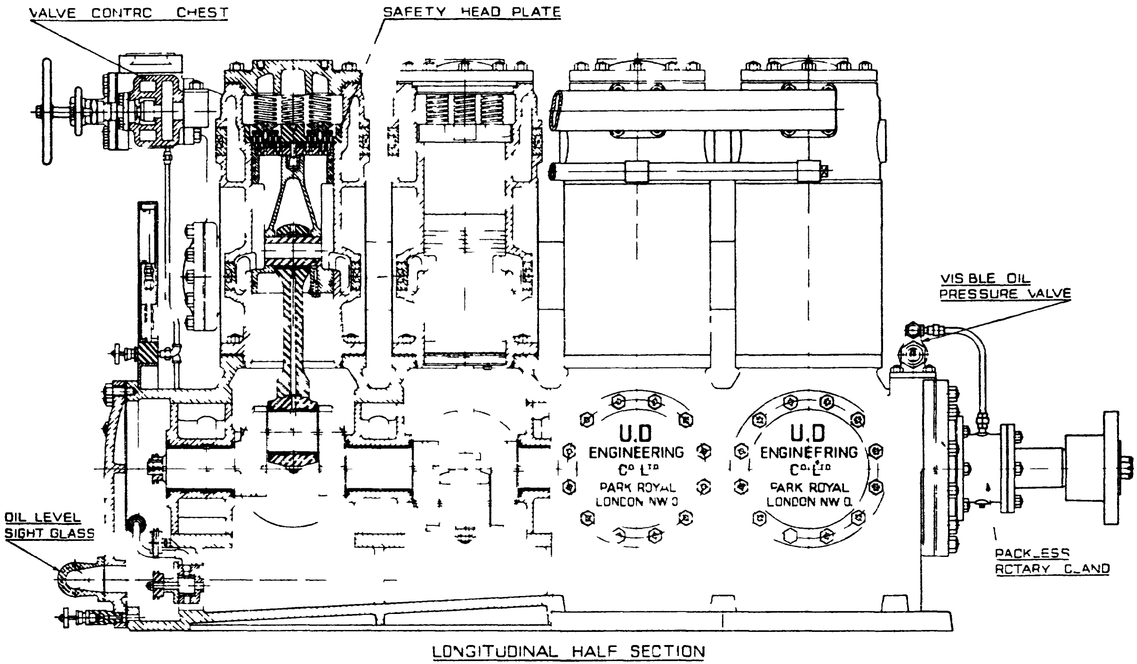
VALVE CONTROL CHEST
SAFETY HEAD PLATE
VISIBLE OIL PRESSURE VALVE
OIL LEVEL SIGHT GLASS
U.D ENGINEERING Co Ltd PARK ROYAL LONDON NW 0
U.D ENGINEERING Co Ltd PARK ROYAL LONDON NW 0
PACKLESS ROTARY GLAND
LONGITUDINAL HALF SECTION

FIG. 45 SECTIONAL ARRANGEMENT OF FOUR CYLINDER UDEC H S V S A AMMONIA COMPRESSOR

(U D Engineering Co Ltd)

Forced feed lubrication is employed for all the moving parts, the pressure being supplied by a gear pump driven from the free end of the crankshaft and mounted so that it is always submerged in the oil contained in the crankcase sump. The oil pressure generated by the pump is also maintained on the packless rotary gland which requires no adjustment and is said to eliminate wear on the crankshaft.

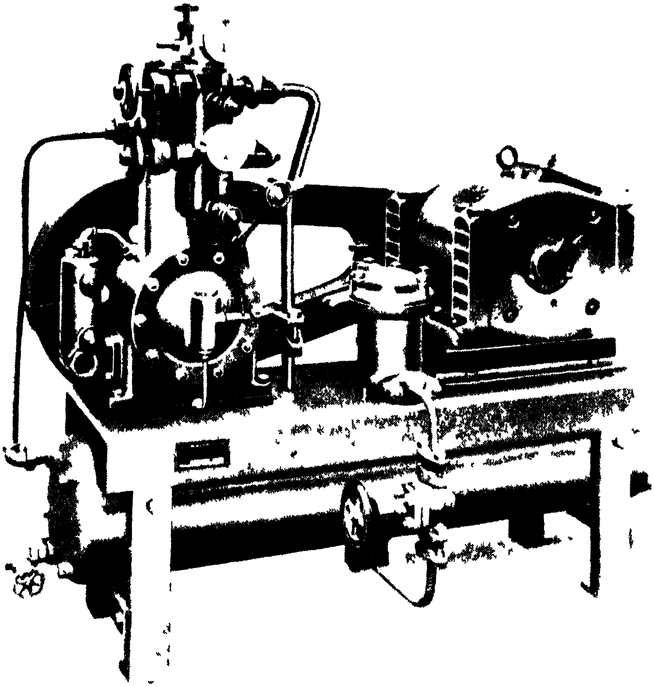

FIG. 16

An interesting feature of these machines is the grouping of all the control valves in a single casing mounted at one end of the machine. This casing carries the main stop valves, cross-over and by-pass valves, and also the safety disc fitting, and results in machines with singularly clean lines.

Fig. 46 illustrates a small self-contained unit in which the shell and tube condenser is carried under the bedplate provided for the compressor, motor and automatic float operated ammonia regulator All the compressors have incorporated in them the same features as the larger machines, such as forced feed lubrication to all moving parts and the packless rotary gland operating under oil pressure.

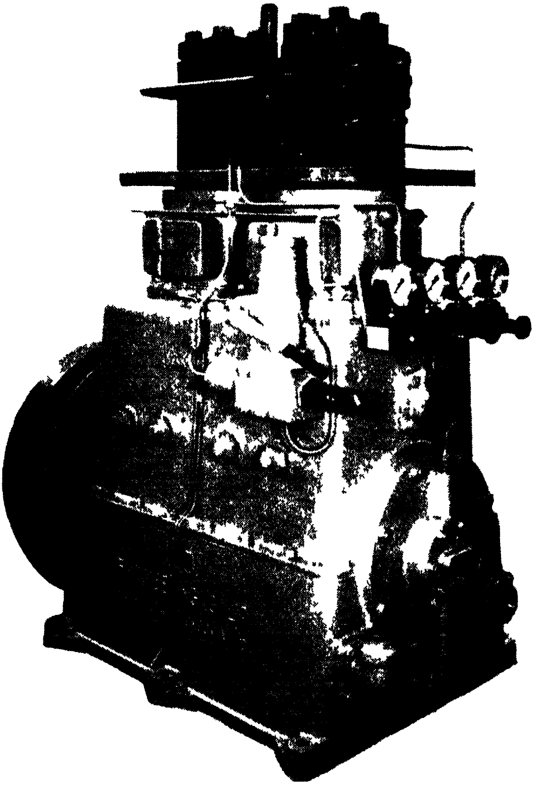

Fig. 47

In addition to the standard compressor described above, the company manufactures multi-stage ammonia compressors for low temperature work or where conditions are such as to make this feature desirable. They also manufacture high speed totally enclosed vertical CO_2 compressors both of the single and multi-stage types. Fig. 47 illustrates a typical example of one of these machines.

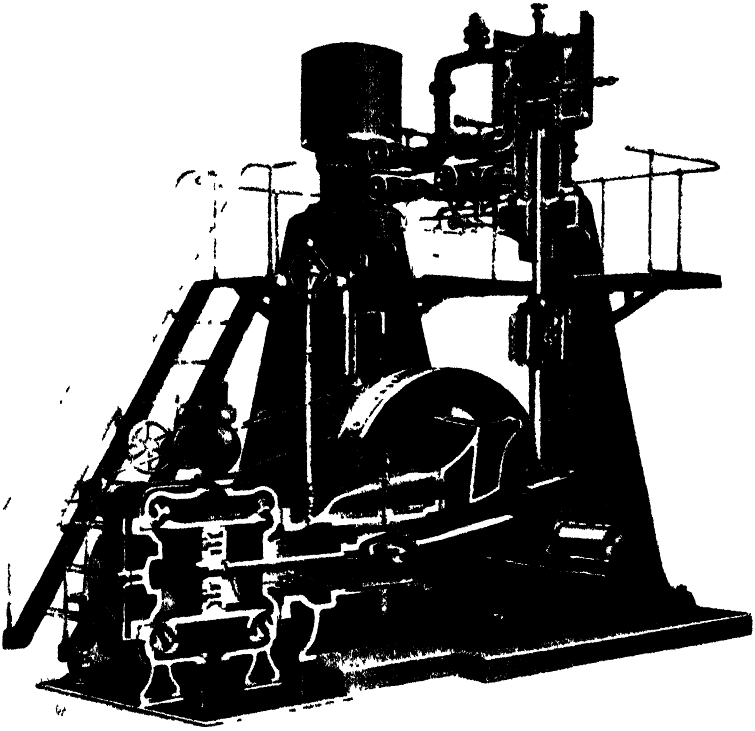

Fig. 48

Machines Built Abroad

The Frick Co.* In this machine the compressors are single-acting, two of them being arranged side by side on the larger machines, and driven by a steam engine which forms part of the complete machine Where electric power is used a motor

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* Messrs The Frick Co., Waynesboro, Pa., U.S.A

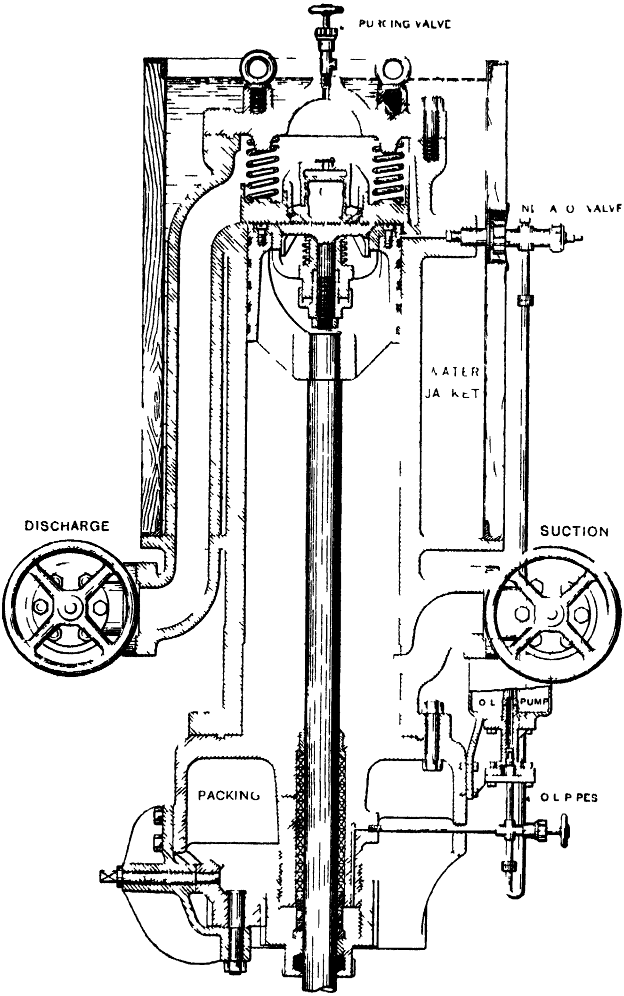
PURGING VALVE
NI A O VALVE
WATER JACKET
DISCHARGE
SUCTION
OIL PUMP
PACKING
OIL PIPES

FIG 49

is sometimes mounted on the main shaft between the compressors.

The general appearance of the machine is illustrated in Fig. 48, while the compressor is illustrated in Fig. 49. The company also make an extensive range of smaller machines, as illustrated in Fig. 50. In both cases the underside of the piston is in free communication with the evaporator coils, and the suction valve is a single large valve placed in the piston itself. The delivery valves are in the compressor safety head, which is entirely independent of the compressor casting. In the event of an accident this allows the complete head to be removed quickly, and replaced by a spare one The machine is worked on dry compression, and the heat of compression is removed by a water jacket, which completely submerges the compressor cover.

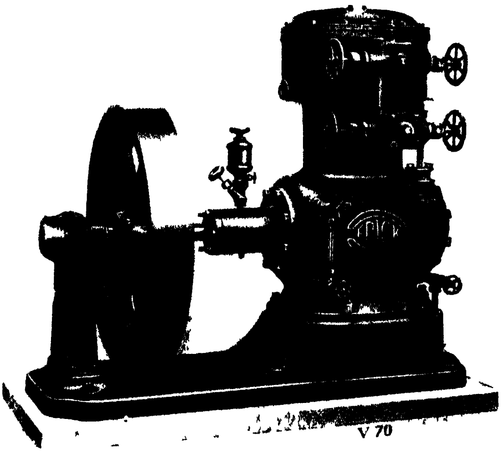

Fig. 50

In the above design, Fig. 50, the piston is of the trunk type, and, as in other designs, the single delivery valve forms the compressor head, and the only gland is on the crankshaft between machine and prime mover, and at suction pressure.

The Sulzer Machines. Messrs Sulzer Bros * took up the design and construction of refrigerating machinery as far back as the 'seventies They manufacture both NH_3 and CO_2 machines The former are the more important, and machines are built in

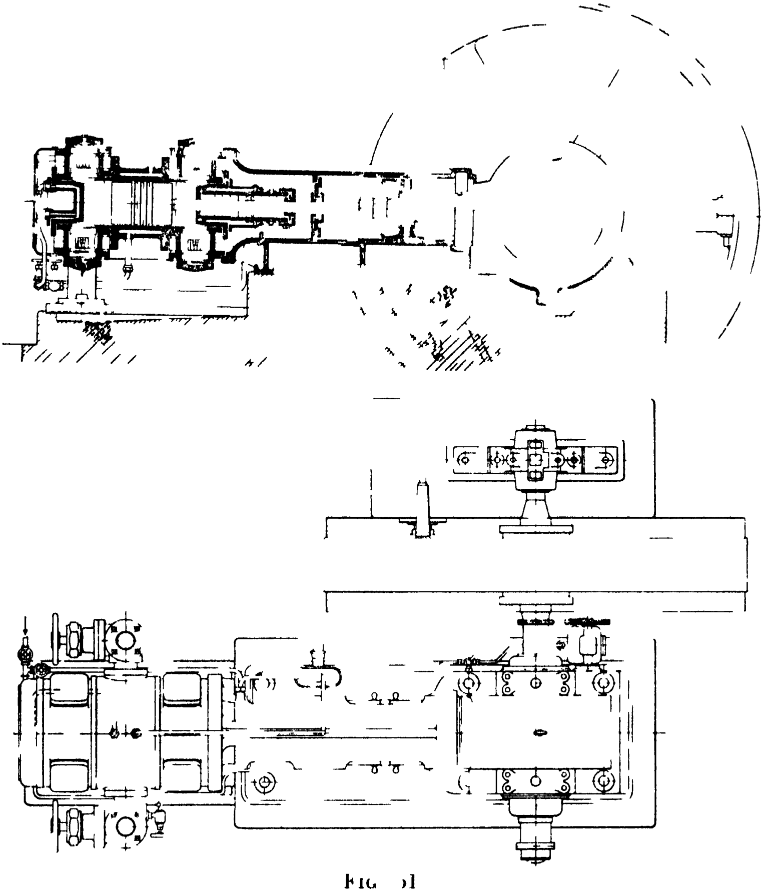

FIG 51

standard sizes, ranging from $\frac{1}{4}$ ton to 600 tons per compressor The smaller sizes up to about 20 tons refrigeration are vertical double-acting with totally enclosed crankcases, whereas the larger units are horizontal, the general design being illustrated in sectional elevation and plan in Fig. 51.

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* Messrs Sulzer Bros Winterthur (Switzerland) and London who have arranged with Sir W G Armstrong Whitworth & Co (Engineers) Ltd to manufacture certain of their specialities exclusively for them at their Scotswood Works Newcastle upon Tyne

The compressors are fitted with spring disc valves of a special quality steel, combining valve plate and spring in one piece. These weigh only a couple of ounces for even the largest compressors, and have an extremely small lift. Owing to these features, and to the absence of friction, the valve works silently, and is practically immune from breakage. At the same time it gives a maximum passage area for the gas, and a minimum clearance. The assembled valve is shown in Fig. 52, and the separate parts in Fig. 53.

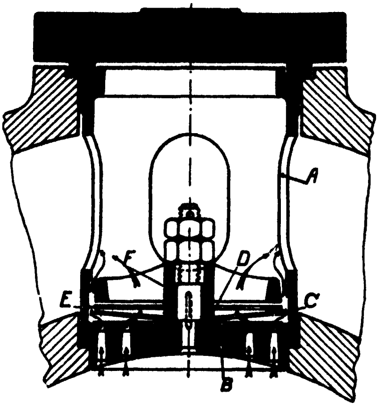

FIG. 52

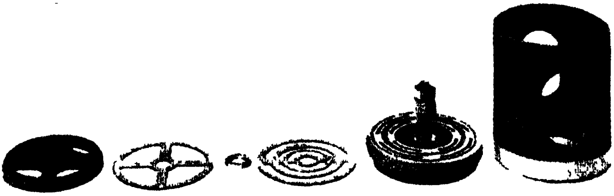

FIG. 53

The castings containing the valves are independent of the cylinder liner and the cylinder covers, and the piston can therefore be withdrawn without disturbing the valves.

Breeches pipes are not necessary, as the interconnections between the front and back end of the compressor are embodied in the cylinder casting This gives the cylinder a very neat appearance The support for the cylinder is independent of the main frame, thus avoiding internal stress due to changes of temperature

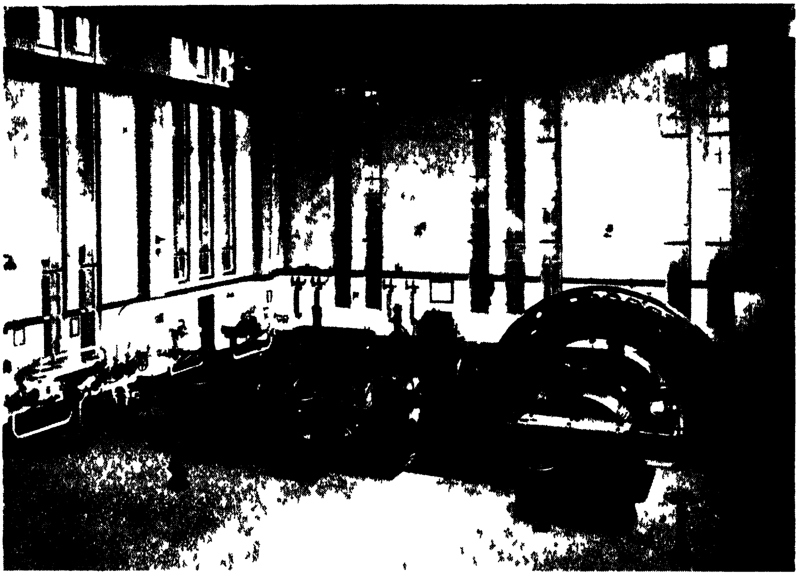

FIG 54

The shaft with double web crank is supported in two main bearings provided with automatic lubrication, and the whole driving gear is totally enclosed. In the case of a belt driven compressor, the shaft is supported by a third ring lubricated bearing beyond the flywheel

With steam engine driven direct coupled compressors, the external appearance and design of the compressor and engine are, with the exception of the cylinder and valves, practically identical.

The compressors are designed for dry compression. Of recent years Messrs. Sulzer's practice has tended more and more to the use of two-stage compressors, as they find that these show advantages over the single stage machine, not only

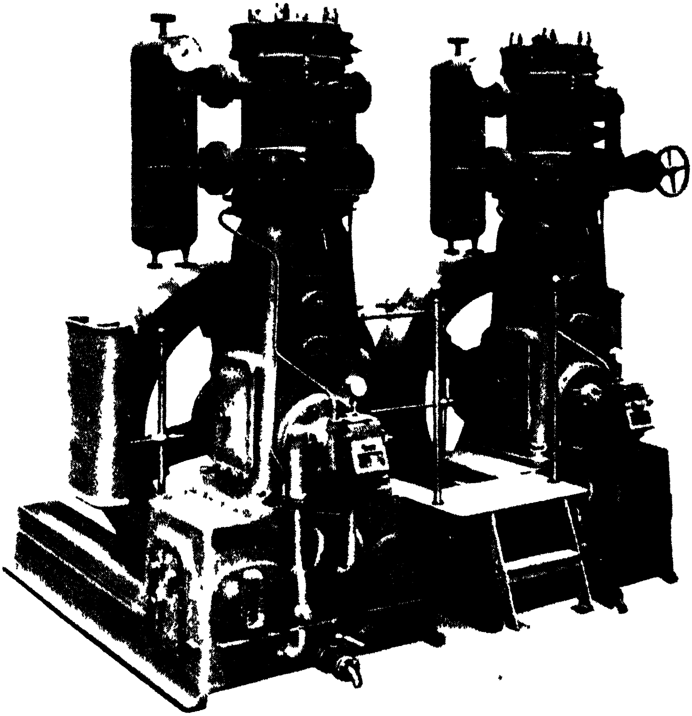

FIG. 55

when working with high condenser pressures, but also in the majority of the temperature ranges that are met with in normal practice. The two-stage compressors are also built in standard sizes for stock, the smaller sizes being vertical and fitted with differential pistons, either single or double-acting The larger sizes are horizontal, double-acting staging again being arranged for by providing stepped pistons, except in the case of very large machines in which separate tandem cylinders are fitted Fig. 54 illustrates one of their two-stage machines driven by flywheel type motor. This is believed to be the largest ammonia compressor unit ever built, being rated to eliminate 32,000,000 B.T.U./hr. with ammonia at a suction temperature of 15° and a forward temperature of 80° F.

Messrs. Sulzers also build special two stage machines for marine purposes, a typical example being shown in Fig. 55, which illustrates two 20 ton machines.

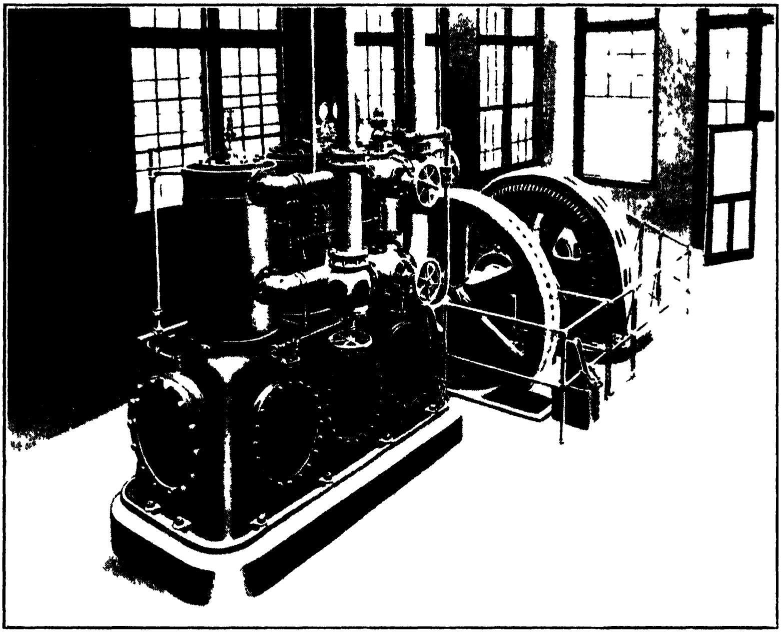

Fig. 56

The York Machines.* Like most other makers of refrigerating machinery, the York Co. have specialized in high speed enclosed machines suitable for direct coupling to an electric motor or a steam engine A three compressor machine, direct coupled to an alternator, is illustrated in Fig. 56, while Fig. 57 is a section through a standard twin compressor machine, and shows the general construction and points of design very

* Messrs The York Manufacturing Co., York, Pa , and York Shipley Ltd., London.

clearly. It will be noticed that in accordance with the best shop practice, the compressors, water jackets, crank case, sole plate, and outer bearing are one casting, the three bearings

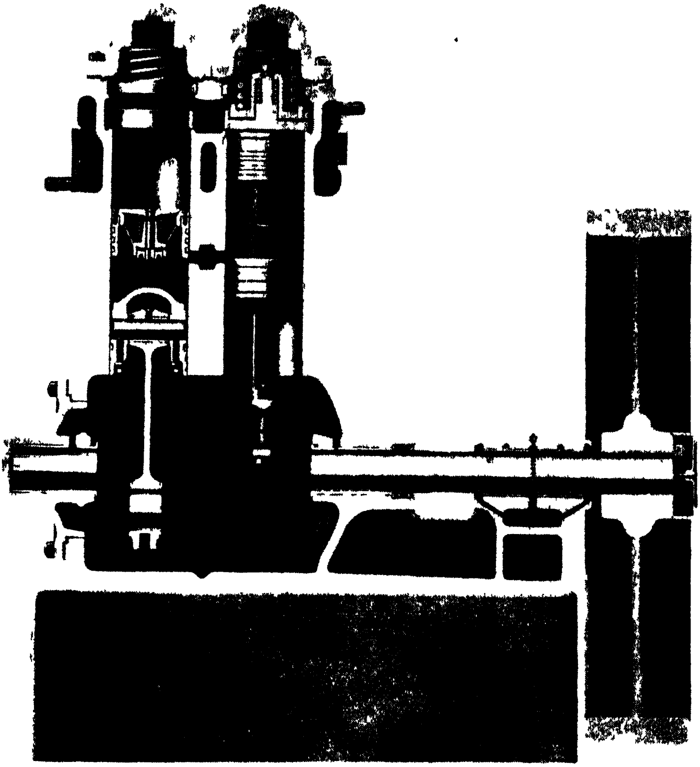

FIG. 57

being bored at one operation. The only gland is the low pressure one on the shaft leading to the prime mover. The water jacket is enclosed, and there is no chance of any ammonia leaking into it from any of the joints. The compressor piston is of the double trunk type, and long enough to operate the suction ports cast in the cylinder. The suction valve is of the flat disc type, placed in the piston head and easily removable without disturbing the piston. The compressors are fitted with safety heads, which, as previously pointed out, is a very wise precaution. The single delivery valve forms the compressor head, and thus gives the maximum area for the minimum lift, a low gas velocity, and the minimum clearance between the piston and the delivery valve. It will be noticed that the compressor covers, the safety head, and delivery valve can be removed without disturbing any pipe connection.

Another point in this design, which is of advantage, is that the suction and delivery pipes can be fitted on either side of the compressor.

CHAPTER VI

THE REFRIGERATING PLANT

Various Ratings. The rating of refrigerating machinery is a subject on which there has been much controversy and it is difficult, if not impossible, to devise a standard unit of capacity to describe the power or performance of a machine that will satisfy both commercial and scientific requirements. This is due to the fact that the performance measured in thermal units of any given machine varies very largely with the conditions of working and that, with the great majority of plants erected in position, it is impossible owing to the disposition and arrangements of the parts, to carry out a test in which the performance in thermal units can be obtained with any degree of accuracy.

There are at the present time two ratings which are generally accepted and in practical use –

(*a*) The ton refrigeration of American origin.

(*b*) The international rating in calories used on the continent of Europe.

The term ton refrigeration dates from the early days of mechanical refrigeration, and was adopted to serve as a basis of comparison of the capacity of the machine with the refrigerating effect that could be obtained by the use of ice.

The latent heat of ice is about 142 B.T.U. per lb., so that the refrigeration effected by one ton of ice passing into water is 284,000 B.T.U., and a machine of one ton refrigeration was taken as being one which would eliminate 284,000 B.T.U. per day in continuous operation.

The pressure and temperature conditions under which this output was to be obtained remained for long indefinite, but were generally assumed to be an evaporating temperature of from 0° to 10° F. and a condensing temperature of from 75° to 95° F.

To make a more convenient unit the ton refrigeration has been taken at 288,000 B.T.U. per day, which equals 12,000 B.T.U. per hour or 200 B.T.U. per minute.

The American Rating. In 1920 a joint committee of the American Society of Refrigerating Engineers and the American Society of Mechanical Engineers investigated the question of a standard rating for the ton refrigeration; their report has now been adopted by the councils of these two societies and is generally recognized as a standard. They state that—

1. A standard ton of refrigeration is 288,000 B.T.U.

2. The standard commercial ton of refrigeration is at the rate of 200 B.T.U. per minute.

3. The standard rating of a refrigerating machine using a liquefiable vapour is the number of standard commercial tons of refrigeration it performs under adopted refrigerant pressures.

A refrigerating machine is the compressor cylinder of the compression refrigerating system, or the absorber, liquid pump, and generator of the absorption refrigerating system.

These pressures are measured outside and within 10 ft. of the refrigerating machine, measured along the inlet and outlet pipes respectively, and are—

(*a*) The inlet pressure is that which corresponds to a saturation temperature of 5° F. (– 15° C.).

(*b*) The outlet pressure is that which corresponds to a saturation temperature of 86° F. (30° C.).

It must be pointed out that this rating applies only to compressors, and that the working of the compressor is very largely dependent on the proportions of the condenser and evaporator. It is therefore open, to some extent, to misconstruction and abuse, but on the other hand it is difficult to see how any rating could be devised which is free from any drawback.

It must also be pointed out that the temperature of the gas coming to the compressor need not necessarily be 5° F. —it may be higher, but it cannot possibly be lower; also, that the 86° F. does not mean that this is the temperature of the gas discharged from the compressor. It is the temperature corresponding to the saturation pressure, and the temperature of the gas delivered from the compressor will, in practically every instance, be considerably higher.

International Rating. In the international rating the capacity of a machine is stated in calories per hour, to be taken when the machine is cooling brine from – 2° to – 5° C. with water entering the condenser at 10° C. and leaving it at 15° C.

Here it will be noted that the machine is considered as a complete unit with no reference to vapour pressures or temperatures, so that the size and efficiency of the condenser and evaporator affect the results obtained.

In this rating the kilogramme calorie is used and the term "frigorie" is often employed, i.e. 1 calorie = 3·96 B.T.U.

British Rating. In 1914 a committee of the Institute of Mechanical Engineers recommended—

1. That the refrigeration produced by a refrigerating machine be expressed in calories per second. This unit is equivalent to 342,860 B.T.U. per day of twenty-four hours.

2. That the refrigeration may be stated for particular conditions or for standard conditions.

3. That the standard conditions be defined as follows. The temperature limits to be steady; the temperature of the cooling water to range from 15° C. (59° F.) at inlet to 20° C. (68° F.) at outlet, and the temperature of the brine to range from 0° C. (32° F.) to – 5° C. (23° F.).

4. That the refrigeration produced under standard conditions be called the "rated capacity" of the machine.

Thus, a machine may be classed as having a "rated capacity of one unit" if it produces a refrigeration of one calorie per second (say, 342,860 B.T.U. per day) in steady working under the standard conditions specified above. Similarly, a two-unit machine is one which, under the same conditions, produces a refrigeration of two calories per second, and so on.

This mode of rating may be taken as applying to absorption machines as well as to vapour-compression machines.

In cases of cooling by direct expansion, without the use of brine, the same method of rating will apply, except that the conditions have to be modified by specifying for the lower limit of temperature that of the working substance itself.

It is considered that a temperature of – 10° C. (14° F.), as a lower limit for the working substance, will harmonize with the conditions which have been laid down for machines using brine, and this figure will also be in accordance with the standards of temperature adopted by the Association Française du Froid.* The committee accordingly recommend—

5. That, in the rating of a direct expansion refrigerating machine, the temperature of the vapour in the evaporator be taken as – 10° C., and that the conditions as regards cooling water be the same as those laid down for machines using brine.

Ice-making Capacity. Machines are frequently described as being of a certain ice-making capacity, i.e. of being capable of making a stated number of tons of ice per twenty-four hours. It is obvious, however, that unless a machine is to be used for making ice only it is quite impossible to test it. The actual number of thermal units required to make a pound —or ton—of ice will vary with the temperature of the water to be used. While the description might be used as an approximate index of capacity, it has sometimes been abused by makers who take only the thermal units required to convert water into ice without taking any external losses into account, and in this way making it appear that the machine is roughly 30 per cent more than its actual capacity.

The Ton Refrigeration. As has been stated, the term ton refrigeration is of American origin, and the American standard rating is generally understood. It, of course, applies to the American or short ton of 2,000 lb. The same rating, but applied to the English or long ton of 2,240 lb. is used by Lloyd's Register of Shipping, as reference to its rules printed on pages 332–7 will show.

The Compressor. The design of an ammonia compressor, or for the matter of that, practically any other machine, is largely a matter of compromise between a number of conflicting factors. It therefore varies considerably with the relative importance attached to these factors by different designers.

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* *Cf.* Professor L. Marchis's paper presented to the Third International Congress of Refrigeration, Washington, Chicago, 1913.

The performance of a well-constructed refrigerating plant approaches so nearly to the maximum theoretically possible that there is not much scope for improvement in actual efficiency. Such as there is lies more with the condenser, evaporator, and auxiliary plant. Improvements are constantly being made in the mechanical details, which enable the efficiency of the machine to be maintained over a long period with freedom from wear and tear, ease and simplicity in operation, and in overhaul when required, and the elimination of the risk of breakdown.

Several types of refrigerating machines have been illustrated in Chapter V. In general it may be said that proved design, and a high standard of workmanship and material, are of the first importance because of the large values and perishable nature of the materials, the preservation of which is dependent on the working of the machine.

The cylinder clearances should be small. The valves of large area, light in weight, and true in operation. The piston speed will be dependent on the relation between the area of the cylinder and that of the valves. The rotative speed on the relation of diameter to stroke, subject, of course, to any limitations of the type of valve employed. Excessive speeds should be avoided but it will probably be found that both piston and rotative speeds are, in all cases, well below the speeds for engine work of similar character where reliability has been for long established.

The bearings should have ample surfaces, with provision for adjustment and automatic lubrication to dispense with the necessity of the man with the oil-can.

The motion work and parts should be of ample strength and the framing or bed plate rigid and constructed to ensure and maintain correct alignment of the working parts.

For high pressure work the gland should be long ; it should be filled with approved packing suitable for the conditions under which it has to work. The machine should be so arranged that there is no difficulty in withdrawing the old packing and repacking the gland when necessary. With high speed, enclosed, single-acting machines, with a rotary gland on the suction side, great length is not necessary, but it is advisable that this type of gland should be geared so that it cannot be pulled up unevenly and bind on the crank shaft.

The machine should run with, as far as possible, an entire absence of noise. It should be of pleasing appearance and well-finished throughout, though this is not necessarily an index of good quality.

Superheating During Compression. In compressing gas in a cylinder, work is done and a certain proportion of the work converted into heat. This reveals itself by raising the temperature of the gas during compression and by raising the temperature of the cast iron cylinder, its valves, piston, and piston-rod and all parts in contact with the hot compressed gas. On the suction stroke cold gas of a certain temperature and volume is drawn into the hot compressor. It will immediately absorb some of the heat from the cylinder walls, piston, and rods, thus raising its temperature, and increasing its volume. The greater the temperature of the gas, the smaller the weight that can be contained in a given capacity. Consequently, the heating of the gas during admission to the compressor results in a less weight of gas being compressed per stroke. As the capacity of the compressor is measured by the weight of gas that can be passed through it per stroke, it is evident that the cooler the parts coming in contact with the incoming gas, the lower the resulting temperature of gas before compression, and therefore the greater the weight for a given volume.

In order to keep the whole of the compression at as low a temperature as possible, the condition of working known as wet compression has been largely employed. Compressor cylinders have also been constructed with water jackets.

Water Jackets. The object of a water jacket is to, as far as possible, remove the heat of compression as it is generated in the cylinder. It is obvious that this can only be effected by jacketing those portions which would otherwise be considerably hotter than the water.

The ammonia entering the compression cylinder is always at a considerably lower temperature than the normal water supply, and observation shows that, in possibly the majority of plants, the suction valve cages and portions of the compressor itself are more or less heavily frosted over.

In a double-acting compressor there is only a relatively small area that can be effectively water jacketed. The gain that can be made hardly justifies the additional expense and complication of the castings involved, so that double-acting compressors are usually unjacketed.

In some cases where a water jacket has been provided for the barrel of a double-acting compressor cylinder, it has been found that the water passing through it has actually been cooled, showing that it has added to the work instead of making any saving.

As a general rule it will be found that only single-acting compressors which have the suction valves in the top of the piston are water jacketed, and that with these the jackets only embrace the upper portion of the cylinder.

Dry and Wet Compression. There has been much controversy as to the relative merits of dry and of wet compression. While it may be shown that, theoretically, the latter gives a slightly greater efficiency, it is found in practice that dry or practically dry compression gives the best results. It is therefore the condition of working aimed at in practically all modern designs.

In wet compression the regulating valve is so adjusted that the liquid is not completely evaporated, and the gas passing to the compressor carries a sufficient amount of entrained liquid. This absorbs, by evaporation, the heat of compression during the stroke of the piston so that the gas is, throughout the stroke and when delivered from the compressor, at a temperature corresponding to its saturation pressure.

In dry compression the gas coming to the compressor is in a dry saturated state, and the delivery from the compressor will be at a relatively high temperature. Some authorities recommend, particularly for single-acting compressors, that to ensure the gas being perfectly dry, it should come back to the compressor slightly superheated, i.e. about 3° to 5° F. above the temperature of evaporation.

It is possible, in wet compression, to run a compressor so wet that unevaporated liquid is discharged from it with the gas. In fact, between the state of completely wet and completely dry compression there must of necessity be a number of intermediate conditions.

It was at one time common practice to provide a liquid connection to the suction pipe on the compressor so that a certain amount of liquid could be injected directly into the suction to ensure wet compression. This is now entirely discarded as a regular working condition, though it is still employed by some operators to keep a compressor cool when it is started up.

Clearance in the Compressor. The effect of clearance in an ammonia compressor is to reduce its capacity. The compressed gas which remains in the clearance space must expand on the suction stroke until it is at a sufficiently low pressure to permit the suction valve or valves to open. Thus, if we assume that the swept volume of a compressor, i.e. the area of the piston multiplied by the stroke is 100, the clearance space 1, and the increase in volume during expansion of the gas remaining in the clearance space from the delivery to the suction pressures is in the ration of 1 : 5, the effective swept volume will be 96, or if the clearance is 2 the effective swept volume will be 91, neglecting any loss of capacity through superheating in the compressor or losses through the valves.

With dry or practically dry compression the extent of the clearance volume is not of such vital importance for, while the capacity is thus reduced, the re-expansion of the gas makes a reduction in the power required. While the reduction in power is not quite in the same proportion as the reduction in capacity, the difference is so small as to be practically inappreciable, provided that the clearance volume is kept within reasonably small limits.

For a given performance a compressor with clearance must have a greater swept volume than one without. It will have a smaller apparent volumetric efficiency, but it does not follow that its true efficiency or ratio of work done to power expended is any less, and this, after all, is the only efficiency that is of direct interest to the user.

If, however, the clearance space contains any liquid ammonia at the end of the stroke, as it may often do with wet compression, this will re-evaporate with the reduction of pressure on the suction stroke, and very seriously affect the volumetric efficiency of the compressor with a consequent serious loss of capacity.

It was this factor which made the question of the reduction of clearance volumes of such great importance when, in the not far distant past, wet compression was almost universally employed.

Testing for Clearance. A very simple way of testing the clearance of a compressor piston is by taking out one of the valves back and front, and inserting a piece of lead wire against the cylinder head. By barring the engine round, the piston is brought against the lead, and squeezes it out to the thickness of the clearance.

If it is undesirable or inconvenient to remove the valves, the engine can be barred round until the compressor crank is on the back centre. Mark the position of the cross-head carefully, then uncouple the connecting rod and push the piston as far back into the cylinder as it will go, and measure the difference. This will represent the clearance. Repeat the process with the front end. In every case, before any attempt is made to ascertain the piston clearance by means of leads, care should be taken to see that all wear is taken up on the connecting rod brasses. Indicator diagrams, of course, give an idea, but it is not always possible to tell by them how much is clearance.

Indicating the Compressor. The method of indicating a compressor, the indicator used, the drum motion, the reducing lever, etc., is similar to that in everyday use for steam engines, the only difference being that for ammonia the indicator, etc., must not be of brass as is common with steam indicators.

The indicator diagram gives an exact measure of the indicated horse-power absorbed in the compressor, and will reveal any serious faults in working such as leaky valves or pistons and incorrect valve springs.

All large compressors should be fitted with indicator connections and gear. Diagrams should be taken at regular intervals and filed for reference. By comparing these with diagrams taken when the plant was first installed, any defects that may develop can be detected and corrected.

In Figs. 58 and 59 two diagrams have been drawn out for a compressor working under the Standard United States Ton Refrigeration Conditions, Fig. 58 being for a compressor with no clearance and Fig. 59 being for a compressor having a clearance volume of 5 per cent of the swept volume.

In these the point *A* represents the end of the suction and commencement of the compression stroke. *AB* is the compression curve, the gas being compressed until at the point *B* the pressure is sufficient to lift the discharge valves. *BC* is the discharge line when the compressed gas is delivered to the condenser, the point *C* representing the end of the compression and the beginning of the suction stroke.

The line *CD* shows the re-expansion of the gas left in the clearance space. The pressure falls in the cylinder as the piston moves forward until it is so reduced that at the point *D* the gas in the pipe can open the suction valves, and the line *DA* represents the admission of the suction gas into the cylinder.

EF is the line of atmospheric pressure taken on the diagram by turning the indicator cock so that the indicator is open to the atmosphere, and *GH* is the line of zero pressure. The adiabatic and isothermal curves are also shown and a dotted line to indicate clearance.

With ammonia the exponent for adiabatic compression is about 1·29, i.e. the curve for adiabatic compression is based on the formula $P\,V^{1\cdot 29} = C$.

It will be found that in dry compression which is now nearly universal, the actual compression line is nearer to the adiabatic than the isothermal. While it will vary slightly with different compressors and the effect of water jacketing, it will be found that an exponent of 1·20 on which these

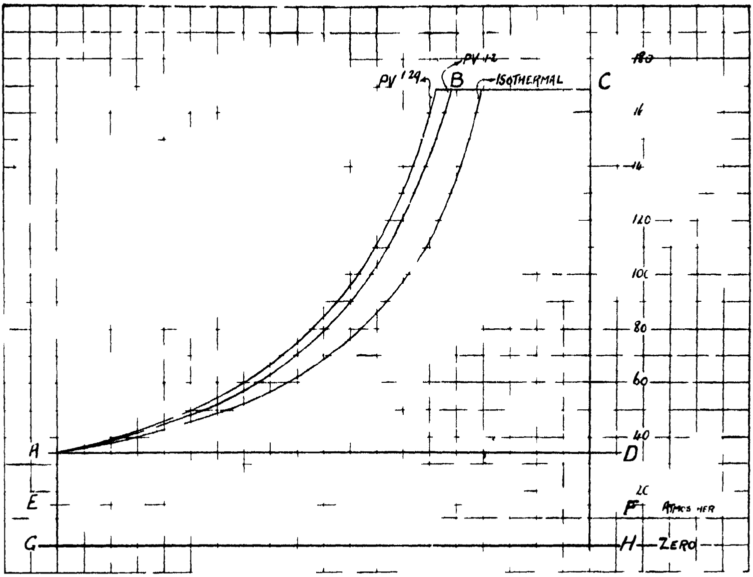

PV 1.29
PV 1.2
B
ISOTHERMAL
C
180
160
140
120
100
80
60
40
A
D
20
E
F
ATMOSPHERIC
G
H
ZERO

FIG 58

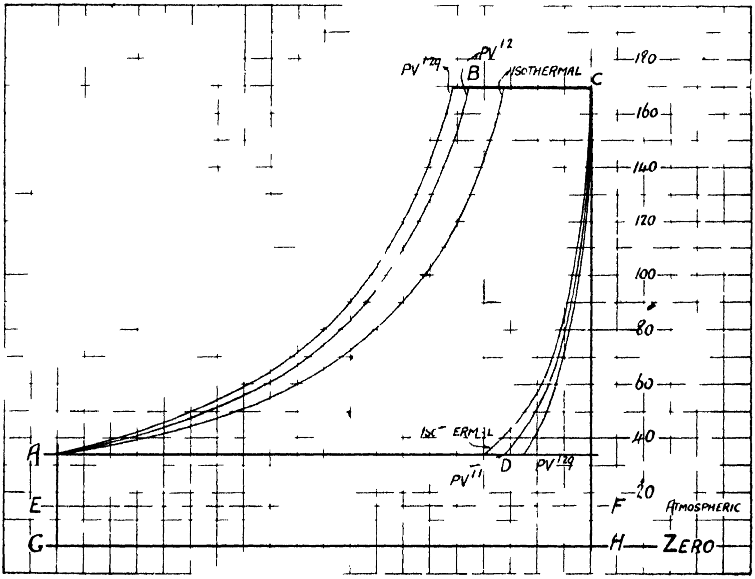

PV 1.29
PV 1.2
B
ISOTHERMAL
C
180
160
140
120
100
80
60
40
ISOTHERMAL
A
D
PV 1.1
PV 1.29
20
E
F
ATMOSPHERIC
G
H
ZERO

FIG 59

diagrams have been drawn, closely represents the average conditions of working.

In examining an indicator diagram, the suction and delivery lines should be compared with the gauge pressures. They should practically coincide with them except at the points where the valves open for the suction and discharge, for to actually open the valves there must, of course, be a difference in pressure.

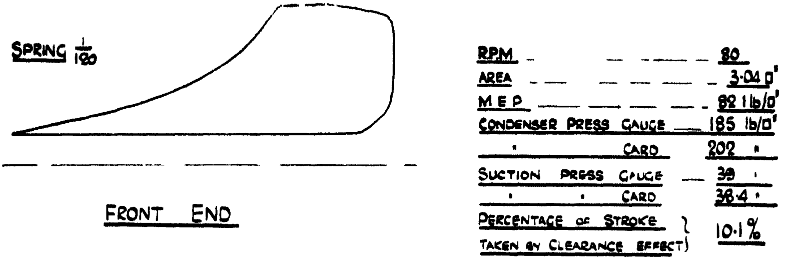
The discharge line will tend to be at a slightly higher pressure than the condenser gauge pressure, and the suction line at a slightly lower pressure than the evaporator gauge pressure. If there should be a difference of more than one or two pounds and the gauges are reading correctly, it shows that there is a restriction of the area through the valves, due either to their being too small, there being too great a tension of the valve springs, or to sluggish action due to their sticking up.

The compression curve cannot lie above the adiabatic line unless there is leakage of gas back into the compressor through the discharge valves or the joint rings of the valve seats. If it should be nearer to the adiabatic than the diagrams taken, when the machine is first installed and in perfect condition, the delivery valves and the jointings of their seats should be attended to and made good.

If the compression curve should fall from its normal position towards the isothermal line, it shows either that there is a leakage at the suction valves or the joint rings of their seats, or a leakage past the piston rings.

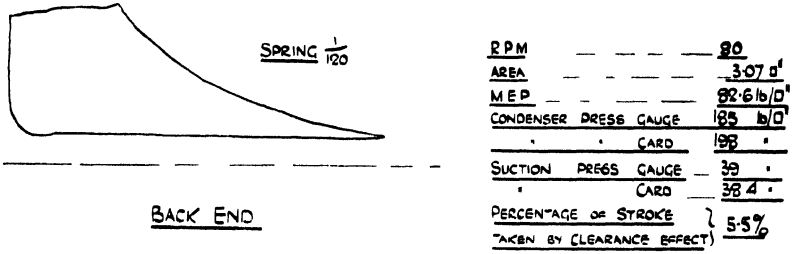
If the diagrams from each end of a double-acting compressor are compared, and the falling away of the compression line only occurs at the one end, it indicates that the suction valves require attention at that end. If both ends are similar, it may be either the suction valves, the piston rings, or both, that require attention.

In the diagram, Fig. 59, it will be noticed that the re-expansion curve is nearer to the isothermal curve than the corresponding curve for the compression. This is due to the fact that the re-expansion takes place in the ends which are the hottest



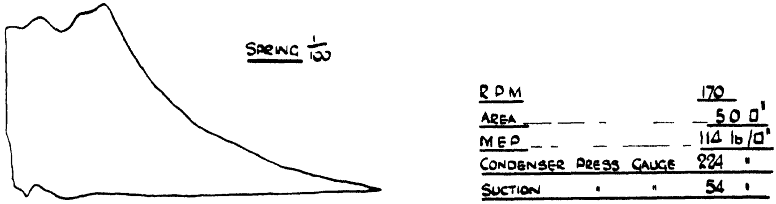
RPM	80
AREA	3.04 □"
M E P	82.1 lb/□"
CONDENSER PRESS GAUGE	185 lb/□"
" CARD	202 "
SUCTION PRESS GAUGE	39 "
" " CARD	38.4 "
PERCENTAGE OF STROKE TAKEN BY CLEARANCE EFFECT	10.1%

Fig. 60
Horizontal NH$_3$ Machine



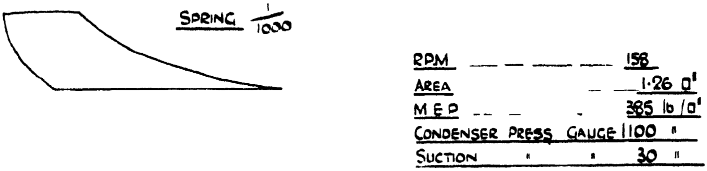
R P M	80
AREA	3.07 □"
M E P	82.6 lb/□"
CONDENSER PRESS GAUGE	185 lb/□"
" " CARD	198 "
SUCTION PRESS GAUGE	39 "
" CARD	38.4 "
PERCENTAGE OF STROKE TAKEN BY CLEARANCE EFFECT	5.5%

Fig. 61
Horizontal NH$_3$ Machine



R P M	170
AREA	5.0 □"
M E P	114 lb/□"
CONDENSER PRESS GAUGE	224 "
SUCTION " "	54 "

Fig. 62
Vertical Single Acting NH$_3$ Machine



RPM	158
AREA	1.26 □"
M E P	385 lb/□"
CONDENSER PRESS GAUGE	1100 "
SUCTION " "	30 "

Fig. 63
CO$_2$ Machine

portions of the cylinder, and the small actual loss of efficiency from clearance is almost entirely due to this.

In Figs. 60, 61, 62 and 63 are shown some actual indicator diagrams that may be regarded as typical examples.

In Figs. 60 and 61, showing the indicator diagrams for the slow speed horizontal double-acting compressor, it will be noticed that the excess of pressure required to open the valves at the end of the compression curve does not fall rapidly, as it should, but that the discharge gradually slopes down, and at the end of the discharge line the pressure on the indicator corresponds to the condenser gauge pressure. The initial excess of pressure appears to be rather greater than it should, and this, together with gradual slope, would appear to indicate a restriction of the opening through the delivery valve, which might be due either to a lack of sufficient area in the passages, or to too heavy a valve spring. The heel of the diagram for the front end is not quite satisfactory, and indicates rather too great a loss from clearance effect. This would appear to be due to a slight leakage back through the delivery valve or its seating, and this view is confirmed by the fact that the compression curve for this front end lies nearer to the adiabatic than does the curve for the back end.

The other diagrams call for little comment as they appear to be perfectly normal, though there is a slight irregularity in the re-expansion curve for the diagram from the vertical single acting machine. This break does not affect the general character of the curve, and is probably due to some slight imperfection in the actuating gear for the indicator.

Horse-power, etc. Though the foregoing are the principal objects of indicating a compressor, it is also useful at times to ascertain the relative horse-power of the engine and compressor. This can be found from the card by the ordinary method of dividing the card up into vertical divisions and obtaining the mean effective pressure (M.E.P.) in pounds per square inch by measuring off the mean pressure in each of the divisions with a scale corresponding to the strength of the spring used in the indicator, adding them together, and dividing by the number of divisions, as in Fig. 64. When the

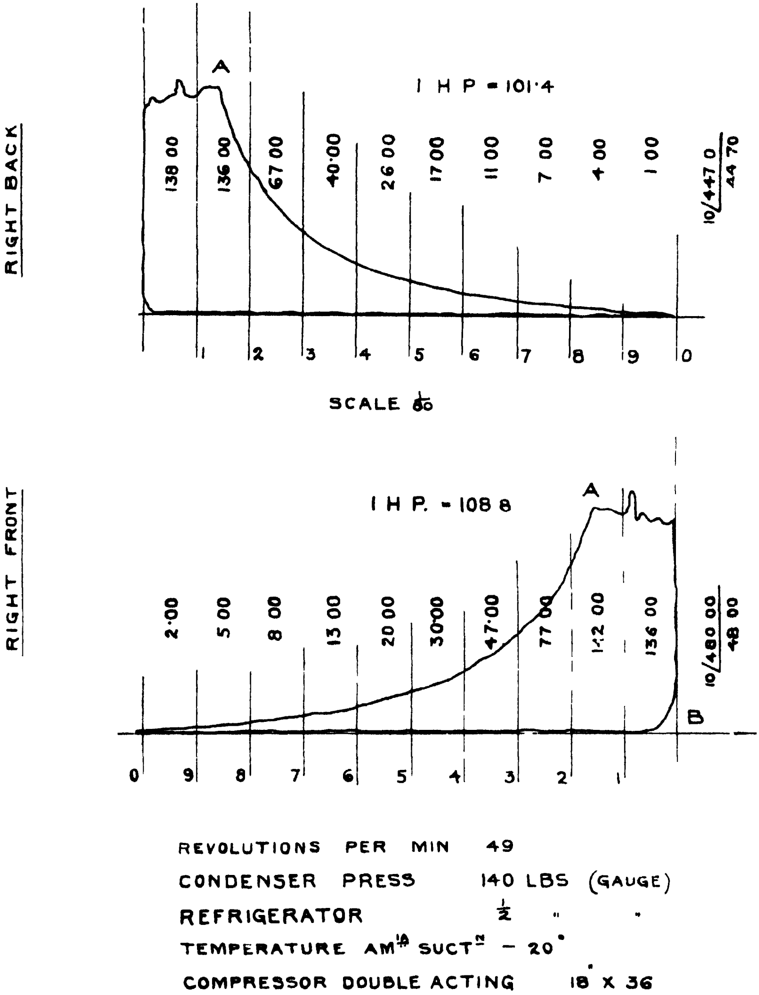

RIGHT BACK
A
I H P = 101·4
138 00
136 00
67 00
40·00
26 00
17 00
11 00
7 00
4 00
1 00
10/447 0
44 70
1
2
3
4
5
6
7
8
9
0
SCALE 1/60
RIGHT FRONT
I H P. = 108 8
A
2·00
5 00
8 00
13 00
20 00
30·00
47·00
77 00
142 00
136 00
10/480 00
48 00
B
0
9
8
7
6
5
4
3
2
1
REVOLUTIONS PER MIN 49
CONDENSER PRESS 140 LBS (GAUGE)
REFRIGERATOR 1/2 " "
TEMPERATURE AM^A SUCT^N − 20°
COMPRESSOR DOUBLE ACTING 18" X 36"

Fig. 64

M.E.P. has been found, it will be necessary to multiply it by the net area* of the piston, the mean speed of the piston in

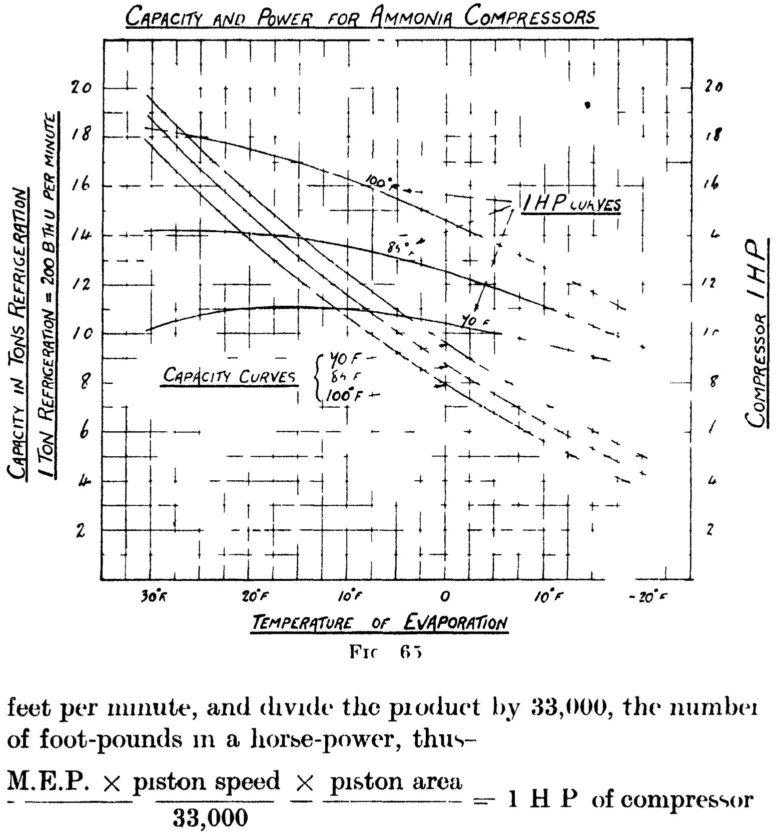


FIG 65

feet per minute, and divide the product by 33,000, the number of foot-pounds in a horse-power, thus—

$$\frac{\text{M.E.P.} \times \text{piston speed} \times \text{piston area}}{33{,}000} = \text{I H P of compressor}$$

If there is no scale handy, the M.E.P. can be easily ascertained by marking off the height of the vertical division continuously on a piece of paper, measuring the total length of these divisions in inches by an ordinary 24-in. rule, dividing by the number of divisions as before, and multiplying the quotient by the scale of the spring. The simplest way of all is to ascertain the area of the card in square inches by one of Amsler's planimeters (they can be obtained from any good instrument maker, and No. 3 is the most suitable), divide the area by the length of the diagram in inches and decimals, multiply this by the scale of the spring, and the result will be the M.E.P. of the diagram or it can be done in one operation

---

* This is usually the full area behind and the area less the area of the piston-rod in front If the compressor or engine has a tail rod, the area of the piston-rod must be deducted in both cases

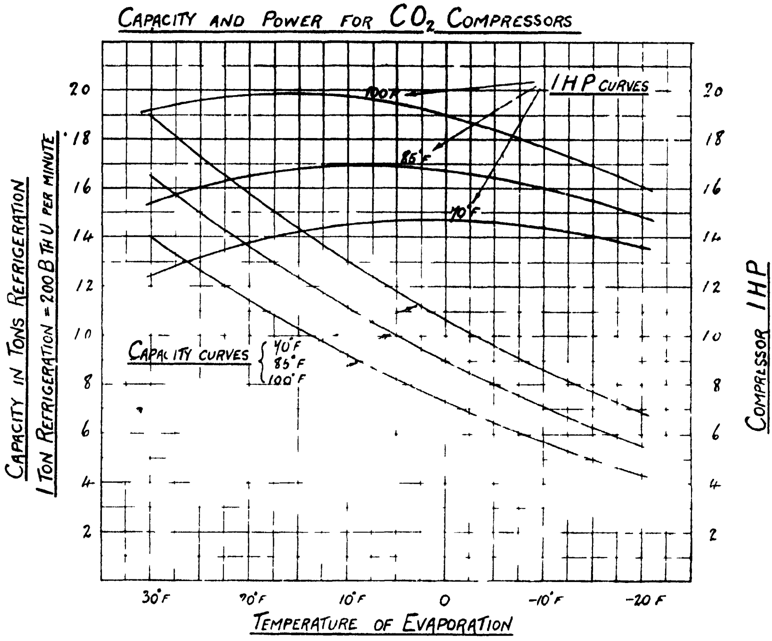


FIG. 66

There are any number of tips for economizing labour in working out diagrams, forming constants, etc., but it would take too much space to set them out here.

Capacity and Power. Diagrams showing the variation in capacity and power required by ammonia and CO_2 refrigerating machines with temperatures of evaporation ranging from 30° F. to − 20° F. with condensing temperatures of 70° F., 85° F., and 100° F., with the liquid refrigerant at the temperature of condensation and dry or practically dry compression are given in Figs. 65 and 66.

The diagrams are only intended to be typical and approximate, the exact form of the curves varying slightly with the characteristics of different makes of machines.

The swept volume in the compressor required for a given capacity also varies from the same cause but, for an output of one ton refrigeration, may be taken as about 8,500 cu. in. per minute for an ammonia compressor or 1,700 cu. in. per minute for a CO_2 compressor.

With very small machines a considerably greater swept volume may be required, with large machines slightly less.

Refrigerating Power Required for Ice Making. The ice-making capacity of a plant means the number of tons of ice that can be made per twenty-four hours in continuous operation. It is obvious that the lower the temperature of the water to be converted into ice, the smaller will be the refrigerating effect and power required for the process. It will also be seen from the above diagram that the higher the temperature of evaporation and suction pressure at the compressor, the smaller will be the swept volume required for a given duty.

Practical considerations which are explained in Chapter X fix the temperature of the brine used in a can ice plant at about 15° F., and it is probable that the ice itself is cooled to very nearly the brine temperature.

To convert 1 lb. of water at a normal temperature of, say, 60° F. into ice, it is necessary to abstract –

The sensible heat of the water 60 – 32 . .	28	B.T.U
The latent heat of freezing	142	,,
The sensible heat of the ice (specific heat 0·5) cooled, say, to 16° F. (32 – 16) × 0·5 . .	8	,,
	178	B.T.U.

The ice cans and frames will have, in an average plant, approximately the same weight as the ice, and must be cooled from, say, 60° to 15° F. There is a certain amount of ice lost in the process of thawing off, loss of heat through the insulation and heat added to the water by the air or agitating devices used for making clear ice. It may be taken, therefore, that a total of about 220 B.T.U. is required to make 1 lb. of ice from water at 60° F., and that with water at higher or lower temperatures the number of thermal units is proportionately increased or decreased.

To make one ton of ice per day from water at 60° F. it is consequently necessary to abstract

$$\frac{2240 \times 220}{24} = 20{,}500 \text{ B.T.U.}$$

per hour, or, converted into refrigerating power, about 1·71 tons refrigeration is required. In the United States, where the ton is of 2,000 lb., the usual allowance for the average conditions prevailing there is 1·6 tons refrigeration per ton of ice per day. As a rough and ready rule, an ammonia compressor capacity of about 16,000 cu. in. swept volume per minute is required per ton of ice per day under these conditions, for plants of, say, five tons per day capacity and upwards. With small ice tanks the various losses are increased, and small compressors also generally require a rather greater swept volume for the same thermal abstraction.

Refrigerating Power Required for Cold Storage. The refrigerating power required to cool insulated rooms is the sum of—

1. The heat passing through the insulation of the walls, floor, and ceiling.

2. The cooling down and possibly the freezing of warm goods that are brought in.

3. The condensation and possibly the freezing of water vapour given off by the goods inside.

4. The changing of the air in the storage rooms involved in normal working, cooling down the fresh air introduced with condensation, and possibly the freezing of a portion of its vapour content.

5. The presence of workmen and use of lights in the rooms.

As all of these factors will probably vary from day to day, it is very difficult to form any reliable and close estimate of the refrigerating power required on the basis of first principles.

It is preferable to allocate the refrigerating power of a plant to be installed on the basis of experience, but it is nevertheless advisable to carefully consider all these factors in the case of any new plant. The leakage of heat through the insulation always forms the largest item, and it is obvious that a store which approximates in shape to a cube will require less refrigerating power than another of equal capacity, but so spread out that it has a considerably greater exposed surface.

A cold store for frozen meat on a dockside receiving cargo direct from the holds of a refrigerated ship will, naturally, require less refrigerating power than a similar inland store. In this case the meat has to be re-cooled and partially re-frozen, due to its transit in an uncooled and insufficiently insulated railway van. With smaller rooms there may be a considerable difference in the power required, owing to the nature of the business in connection with which they are employed, the extent to which the room is used, and the number and length of times that the doors are opened during the day.

To ensure satisfactory results it is essential to have an ample though not excessive margin of power in the refrigerating plant, and the diagram (Fig. 67) opposite has been prepared to give an index of the refrigerating power which should be provided for ordinary cold storage purposes.

In order to cover a wide range this diagram has been plotted on a log scale.

The refrigerating capacity is based on the capacity of the machine in United States Standard Ton Refrigeration.

The capacity of the room or rooms in cubic feet is based on the gross capacity inside the insulation, and should include any air cooler enclosures or pipe lofts.

Where several rooms adjoin each other so that they form in effect a single store with partition walls, the refrigerating power should be based on the total capacity of the rooms, but with an installation comprising two or more independent spaces, the sum of the refrigerating powers for each individual space should be taken.

The refrigerating power is given on a twenty-four hour basis.

and for reduced hours of working must be proportionately increased.

The diagram must not be used for rooms to be used solely for the freezing or chilling of meat or other special purposes

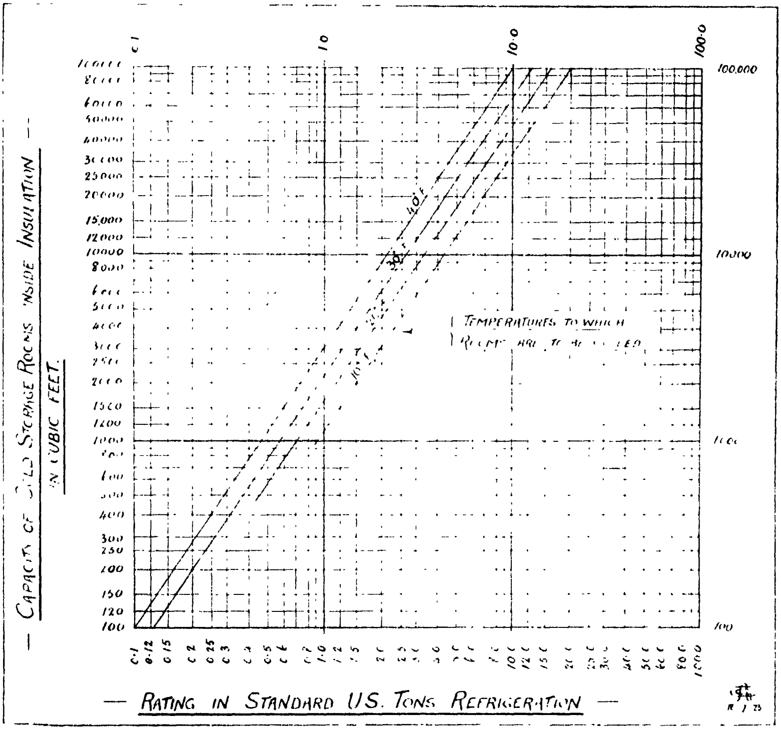


FIG. 67

where the refrigerating power required for dealing with the goods inside the rooms forms the greater portion of the load.

For stores of larger capacity than 100,000 cu. ft. the refrigerating power should be taken in direct proportion to the capacity. In hotels and restaurants, where there are frequently a number of very small compartments widely separated and with long pipe leads, and the service often very severe, it may be advisable to increase the power as found by the diagram by from 50 to even 100 per cent.

It is assumed that the spaces to be cooled are efficiently insulated throughout with a thickness of about 1 in. of compressed cork slabs (or an equivalent thickness of other suitable material) per 10° F. difference between the temperature to which they are to be cooled and the normal maximum average temperature outside. For this country the thickness of cork slabs should be about—

For an inside temperature of 35°	4 in.
„ „ „ „ 15°	6 in.

Taking two examples. (1) A frozen produce warehouse of 50,000 cu. ft. capacity, built to comply with Lloyd's requirements and fitted with two machines each capable of performing the duty required in eighteen hours' working. The 50,000 cu. ft. at 15° F. will require about 11 tons refrigeration per twenty-four hours, so that each machine should be of

$$\frac{11 \times 24}{18} = 14{\cdot}7$$

or, say, 15 tons refrigeration. (2) A butcher's room of 1,000 cu. ft., where the hours of working are to be limited to from eight to nine per day. The 1,000 cu. ft. cooled to 35° F. requires about 0·5 ton refrigeration per twenty-four hours, or we require a machine of about 1·5 tons refrigerating power.

Oil Separators. If lubricating oil from the compressor is admitted into the system, it accumulates in the evaporator pipe system and causes inefficient working by forming a coating or film over the inside of the pipe surfaces, which seriously affects the rate of heat transmission through them.

To prevent this, every plant should have a separator vessel in the discharge pipe between the compressor and condenser.

When a compressor is run on dry compression the discharge is hot, and as the lubricating oils used have a relatively low flash-point, it is probable that some fractions become vaporized. For this reason it is found that the best results are obtained when the separator is placed at some distance from the compressor, where the discharge gas will have somewhat cooled down and any oil vapour will have condensed.

The separator vessel is provided with a drain valve so that any oil collected in it can be drawn off. The oil, however, under the high delivery pressure contains a considerable amount of ammonia in solution which is given off in the open air, and to avoid the loss of this ammonia and the smell, the drain from the separator is frequently connected to another vessel which is, in turn, connected with the suction side of the compressor. The oil is discharged into this vessel, the drain valve on the separator is then closed, and the valve on the suction connection opened. With the reduced pressure the bulk of the ammonia in solution in the oil will be driven off, and the oil can then be removed from an open drain valve on the second vessel, and the escape of ammonia gas involved in the process reduced to a minimum.

Trouble with lubricating oil in the system frequently occurs with the enclosed type of compressors. With these the separator is frequently very close to the compressor, and the drain is connected to the crank case so that the oil can be blown back directly into the machine.

Although some makers deprecate this arrangement, it seems to be generally satisfactory. It would appear, however, that when it is followed a second separator placed as close as possible to the condenser would be advisable.

The Condenser. The function of the condenser is to get rid of the heat of liquefaction and compression, and thus to liquefy the gas passing through it. Condensers are merely devices for exchanging heat from one substance to another. and it must be borne in mind that the greatest theoretical efficiency can be obtained when the fluid or gas to be condensed comes into direct contact with the condensing medium. This, however, is impossible of adoption in those cases where it is necessary to prevent the fluid or gas from intermixing with the condensing medium and, therefore, it becomes necessary to introduce separating walls between the two ; so that the efficiency of the condenser depends upon the transmission of heat from the gas and vapour upon the one side of the separating wall, to the condensing medium upon the other.

It has been found that the transmission of heat is practically independent of pressure ; that for a given range of temperature the heat transmitted is nearly proportional to the velocity of the cooling water ; and that with the same temperature, range, and velocity more heat is transmitted at the higher temperature. The moral of this is plain—make the condenser of as good a conductor as possible. Pass the water over the condenser surfaces rapidly, and let the warmest water meet the warmest gas, and the coldest water the coldest gas.

On the efficiency of the condenser of an ammonia or CO_2 refrigerating machine depends in a great measure the economical working of the plant. Practical considerations, such as first cost and space, must have an important influence on design, but where other considerations are not outweighed by these two, it is good practice to have as large a condensing surface as is within reason possible. A glance at the curve of ammonia, Fig. 9, will show the necessity, with this agent, of keeping the condensing temperature, and so pressure, as low as possible. The same thing applies to CO_2, but there the rise in pressure is less rapid.

With evaporative open condensers, the surface can, of course, be overdone, the reason being that this type of condenser depends for its efficiency on the cooling due to the evaporation of the water passing over it. The cooling, due to evaporation, is shown by the fact that, on a dry day, the water has been found leaving the condenser at a lower temperature than that at which it went on.

Types of Condensers. Refrigerating condensers are made in three general types—

1. The submerged condenser.
2. The open condenser.
3. The double-pipe condenser.

Ammonia condensers have been made of the shell type, where the construction is generally similar to that of a surface steam condenser with a welded steel shell to contain the ammonia condenser, and welded in steel tubes through which the water passes, but their application has been so limited that they can practically be neglected.

Submerged Condensers. In the submerged condenser, the coldest water always meets the coldest gas, and the temperature range is maintained, but the movement of the water over the coils is sluggish, and does not assist the rapid interchange of heat. For this reason more water and more surface are required than with the other types.

The nesting of the coils and the contracted space make cleaning difficult, and small bubbles of air are apt to collect on the coils, which by their insulating effect further retard the heat exchange.

For marine work the submerged condenser, owing to its enclosed form, is the most suitable type. This, and the small amount of space occupied, seem to be the chief advantages it can claim, though, undoubtedly, where compactness is desired, as in a self-contained plant, they are considerations of great importance. One great disadvantage of the submerged condenser is that, owing to the readiness with which water absorbs ammonia, a leak, unless serious, is never discovered, as few engineers take the trouble to test their condensing water. As an illustration of this, on one occasion a coil in a submerged condenser on shipboard split, the ammonia began to escape into the sea-water, and the driver was unable to account for the deficiency in the plant. The whole charge was only prevented from escaping by the formation of salammoniac, which stopped the leak Another point is that in order to clean or repair a submerged condenser, the coils have to be taken out of the tank, which usually involves great trouble.

An increased velocity of the water over the pipe surfaces can be obtained by fitting stirring gear in the centre of the coil space, but this involves some additional power and the arrangement of an extra drive. Moreover, except in quite large sizes, it is probable that there is very little if any advantage from the point of view of first cost, as the gain in heat transmission secured by the stirring gear could be equally well obtained at the same extra cost by additional pipe surface.

The Open Condenser. The open condenser consists of a coil or sets of coils of piping made up in a vertical plane and provided with a slotted pipe or water distributing trough

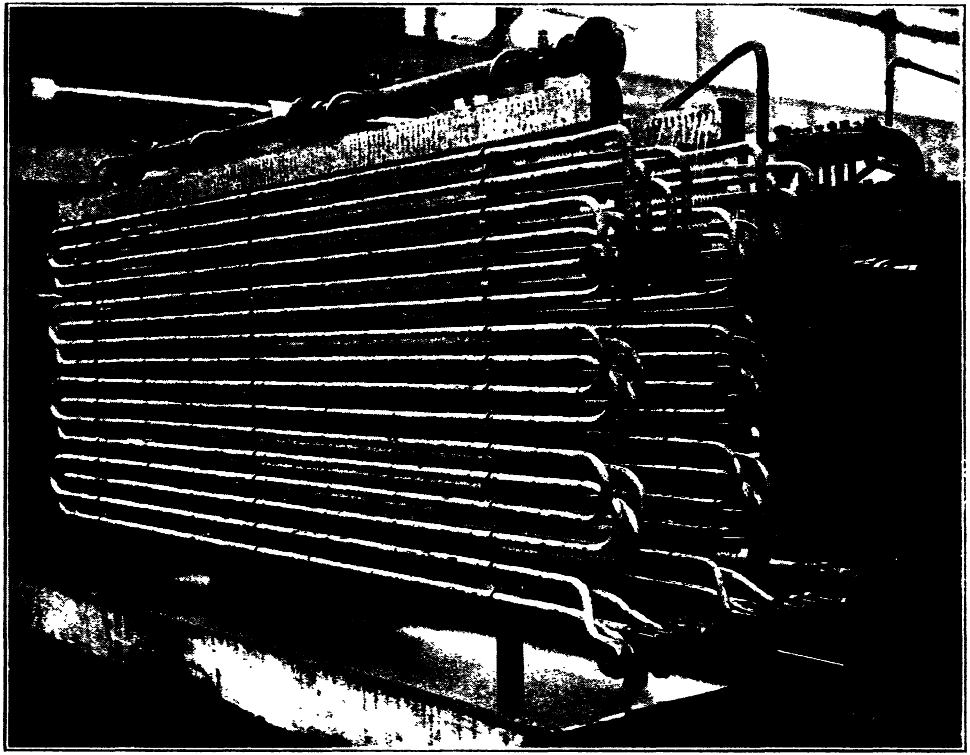


FIG. 68

at the top, to give an even flow of water over the pipe surfaces.

The coil or coils are erected over a tank for collecting the water flowing off them, and they are generally placed in an exposed position on the roof of the building. In these positions the condenser should be surrounded by louvre boards, to permit free access of air and at the same time prevent the water being blown off the pipes in high winds.

Open condensers may be subdivided into two general types—

(*a*) The atmospheric or evaporative type, generally constructed of continuous welded coils with three interlaced coils on each stand and made sufficiently large to serve also as a re-cooling tower, so that the same water can be continuously re-circulated and the make-up supply limited practically to that required to make up the loss by evaporation with spray and windage losses.

(*b*) Condensers of smaller surface generally built up of straight piping and fittings, and either of what are known as the flooded or of the bleeder systems.

In the former type (*a*), which is typically illustrated in Fig. 68,* the gas is admitted at the top, and the liquid is taken away from the bottom of the coils, and as the heat of condensation throughout the condenser is balanced by the evaporative cooling of the water, the water itself remains at a practically constant temperature in its passage over the surface of the condenser piping. The temperature of the water then is governed by the atmospheric conditions prevailing and the efficiency of the condenser as a cooling tower.

In the latter type (*b*), illustrated in Fig. 69,† the gas is generally admitted at the bottom, and brought into contact with a portion of the condensed ammonia (hence the name flooded type). The passage of the mixture of gas and liquid is upwards, and the liquid which is to pass to the evaporating side is drawn off at one or more points in the height of the condenser.

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* Messrs. L. Sterne & Co., Ltd., Glasgow.

† Messrs. J. & E. Hall, Ltd., Dartford, Kent.

By this means a counter current effect is obtained and a higher over-all rate of transfer of heat is obtained per unit of area. The reduction in the size of the condenser that can be obtained in this way has the disadvantage of so lessening its evaporative efficiency that it is necessary to have plenty of water and run it to waste or to use a cooling tower or water cooler.

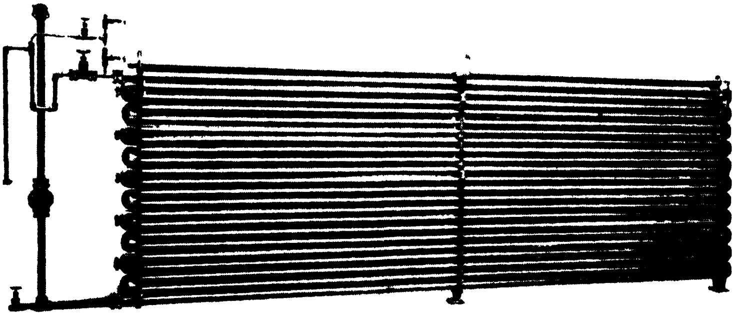

FIG 69

With open condensers strips of iron are generally placed between the pipes to guide the water from one to another and avoid splashing. In the larger evaporative type condensers these strips are seldom used, as the pipes are usually closer together. To some extent they prevent free air circulation, and when the water is re-circulated a certain amount of splash may be of advantage in increasing the evaporative efficiency of the condenser considered as a cooling tower.

In some cases, where no suitable exposed site is available, atmospheric condensers have been placed in a room or space through which a current of air is created by a fan, and good results have been obtained in this way.

The Double-pipe Condenser. The double-pipe condenser consists of a coil or stand of pipes and each pipe or lap of the coil consists of two pipes, one threaded inside the other. By means of suitable fittings the ends of the inner pipes through which the water passes are connected together to form a single coil. The annular space between the two pipes, which serves as the condensing space for the ammonia, is also connected together at the ends. A typical example is illustrated in Fig. 70.*

The ammonia gas enters at one end at the top, and the liquid is taken off at the bottom ; the water enters at the bottom, and leaves at the top, so that the effect is strictly counter-current. Owing to the high velocity of the water passing through, and also, though to a smaller extent, the high velocity of the entering ammonia gas, the rate of heat transfer is high, so that the condenser is an efficient type. Its construction enables the dimensions to be readily varied within fairly wide limits to suit the space available. No water passes over the outside so that there is no splashing, and the condenser can be placed in any desired position. As the water circuit is enclosed and will withstand any reasonable working pressure, the overflow can be taken directly to an overhead service tank or to any other position.

The inner pipe is usually made of 1¼ in. pipe, and the outer of 2 in. pipe, and the return connections are of semi-steel or malleable castings. This involves a somewhat large number of joints, but there is no difficulty in keeping them tight and as separate straight pipes and fittings are used, it is a simple matter to replace one if it should be split or become corroded.

To avoid the large number of joints, double-pipe condensers are sometimes made with the ammonia circuit completely welded up. It is doubtful if this is of advantage except in small sizes, for if a single pipe goes it is probably necessary to renew the whole condenser—or section, if there is more than one stand. It is possible also that considerable strain might be thrown on the welds, due to differences in expansion or contraction of the two pipes.

Some double-pipe condensers are made with the ammonia in the inner pipe and the water passing through the annular space. This would appear to have the serious disadvantage that it would be very difficult if not impossible

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* Messrs. Peter Brotherhood & Co., Ltd., Peterborough.

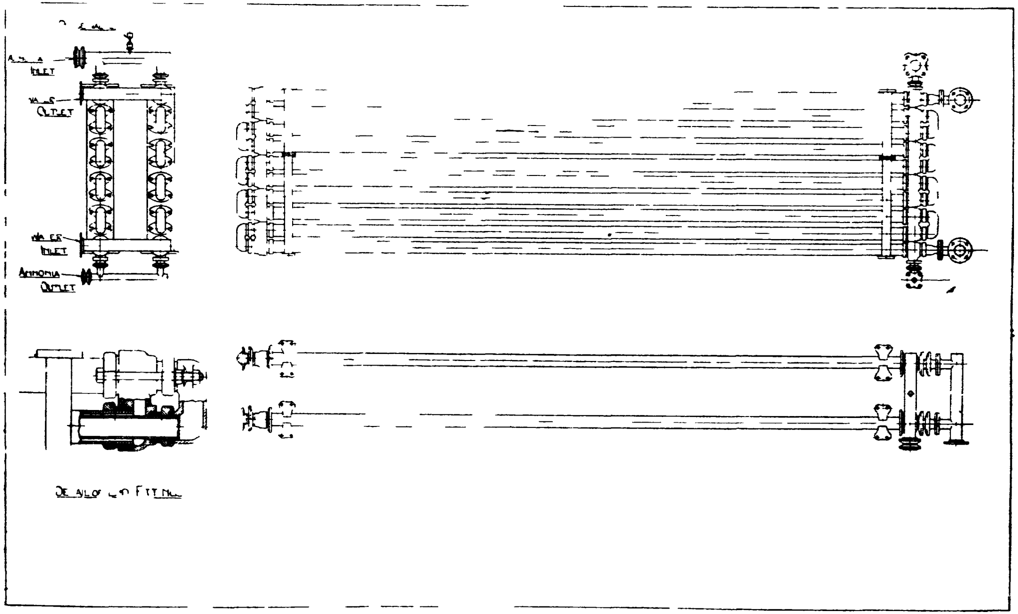
AMMONIA INLET
WATER OUTLET
WATER INLET
AMMONIA OUTLET
DETAIL OF END FITTING

FIG. 70

to clean out any sediment or deposit that may be left by the water.

Messrs. Sulzer Bros. have recently introduced a plate condenser for small plants. This is illustrated in Fig. 71, and consists of a coil of pipes fitted into a recess stamped in steel plates, which forms the water space. For cleaning purposes the plates are removed. Where the water supply is foul this design has advantages.

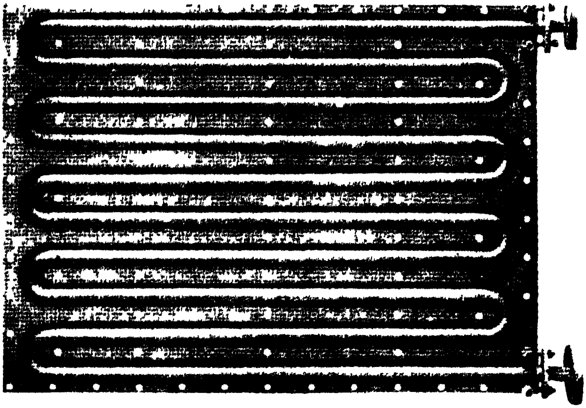

FIG. 71

Size of Condensers. The condenser pipe surface usually provided, per ton refrigeration, is approximately, in submerged condensers, about 30 sq. ft. or, say, about 80 ft. of 1 in. or 70 ft of 1¼ in. pipe. In double-pipe condensers about 7·6 sq. ft. or, say, 17 to 18 ft of the inner 1¼ in. pipe exposed to the ammonia. In open condensers of the flooded type about 10 sq. ft. or, say 16 ft. of the 2 in. pipes, of which these are usually built. In the interlaced coil type condensers about 25 sq. ft. or, say, 60 ft. of 1¼ in. is a usual allowance, but where the make-up water supply has to be reduced to a minimum, these are often made considerably larger to increase their evaporative efficiency rather than their efficiency as a condenser.

The condenser must be proportioned to suit the actual duty the machine has to perform, and must not be based on any nominal rating or capacity. Thus a machine rated at, say, 10 tons refrigerating power, under the United States Standard Conditions, will actually give about twice that output in thermal units if used for water cooling and run with an evaporating temperature of about 30° to 31° F. Under these conditions, therefore, it would require a condenser normally suitable for a machine of 20 tons capacity.

Water Required. The whole of the heat extracted by a refrigerating plant, plus the heat equivalent of the work done in the compressor, is discharged into the condensing water. The quantity of water used and its rise in temperature are therefore mutually interdependent; to reduce the quantity of water will increase the condensing pressure and power required, and conversely to increase the quantity will decrease the pressure and power required.

The quantity of water used should be determined by the relative costs of power to drive the compressor, and the cost of water when this has to be paid for by meter, or the cost of pumping it from a well or stream.

With open type condensers the minimum quantity which will suffice to keep the surfaces properly wetted is about 5 lb. per foot run per minute, and the best results are obtained with about 1½ or 2 gallons per minute per foot run of condenser stand. When an atmospheric condenser is used and the same water supply is continuously re-circulated, it is an advantage to circulate a large quantity of water, for though a considerable portion of it may splash off the pipes, it will in this way increase the efficiency of the condenser considered as a re-cooling tower.

With submerged or double-type condensers the quantity used is in direct proportion to the rise in temperature, thus one ton of ice-making capacity represents about 28,000 B.T.U. per hour to be passed into the condensing water, which represents—

560	gallons	rising	5°
280	,,	,,	10°
187	,,	,,	15°
140	,,	,,	20°

The temperature corresponding to the ammonia delivery pressure will be practically a constant figure in excess of the temperature of the overflow water, and the variation in the power required with the variation in the water supply can be estimated from the curves given.

Getting Air out of Condensers. It is of great importance that the ammonia in a plant should be as pure as possible as any air or other permanent gases seriously affect the rate of heat transmission and, therefore, increase the condensing pressure and the power required to drive the compressor.

Any air in the system tends to accumulate in the condenser, and a purge valve should be provided at the top of the condenser so that it can be discharged when necessary.

Owing to the diffusion of gases it is not practicable to separate air from ammonia gas inside the condenser, and before purging the condenser should therefore be, as far as possible, filled with ammonia in the liquid state to avoid loss of gas that would otherwise be blown out.

To do this the ammonia or outlet valve should be closed, and the machine kept running with water flowing through or over the condenser until the delivery pressure is fairly high —say 200 lb. per sq. in. The machine should then be stopped, the ammonia inlet valve to the condenser closed, and the water service left on. The pressure will then fall slightly, and when the gauge is steady the inlet valve can be opened and the machine run slowly; the pressure will then rise rapidly. When it again reaches say 200 lb. the machine should be stopped, and the water service left on for a further half an hour or so.

The purge valve should have a small pipe connected to it, leading down below the surface of the water in the tank or, in the case of a double-pipe condenser, into a bucket or tank full of water.

When the purge valve is opened slightly the air will escape and show its presence by bubbles in the water, and the ammonia will be dissolved in the water with a sharp crackling sound.

On first opening the valve the escaping gas will be almost entirely air; after a little while there will be both air and traces of ammonia. As the bubbles of air diminish in volume the crackling noise due to the ammonia will increase, and as soon as the bubbles practically cease the valve should be closed.

Where there are several stands or sections in the condenser, these can be purged in rotation by closing the inlet valve to that section, and leaving the water flowing through or over it for some hours.

When carried out with care in the manner described, purging can be effected with but little loss of ammonia. The operation is, however, only too often limited to opening the purging valve and blowing off at some time when the machinery is not working, with the result that large volumes of ammonia are lost, and the air or other non-condensable gases are not entirely removed.

To facilitate the effective purging of refrigerating installations with the minimum loss of ammonia, most manufacturers can now supply a special non-condensable gas purger, one example of which is shown in Fig. 72.* The apparatus consists of a cylindrical vessel, inside which is a coil of steel tube. The bottom of the vessel is fitted with a loose cover having a projection downwards fitted with a sight glass *D* and stop-valve *C*; there is also a branch for stop-valve *G*. On the body of the vessel are arranged a pressure gauge *F*, relief valve *E*, liquid level gauge *H*, and thermometer pocket *J*. The connections to the coil pass out of the top cover. The inlet has a T-piece, one branch of which is connected to the main liquid line from the condenser through a regulating valve *B*, and the other branch to the stop valve *G* on the lower cover. The outlet end of the coil goes to the compressor suction, and has a stop valve *A*. The non-condensable gases enter the vessel through valve *C*. In operation the stop-valve *A* is opened fully, and liquid ammonia is allowed to enter the coil through the regulator *B*; this causes a fall in temperature inside the vessel. When the stop-valve *C* is opened the non-condensable gases and a certain amount of ammonia gas enter; the latter is condensed to liquid and remains in the bottom of the vessel.

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* **Messrs. J. & E. Hall, Ltd., Dartford, Kent.**

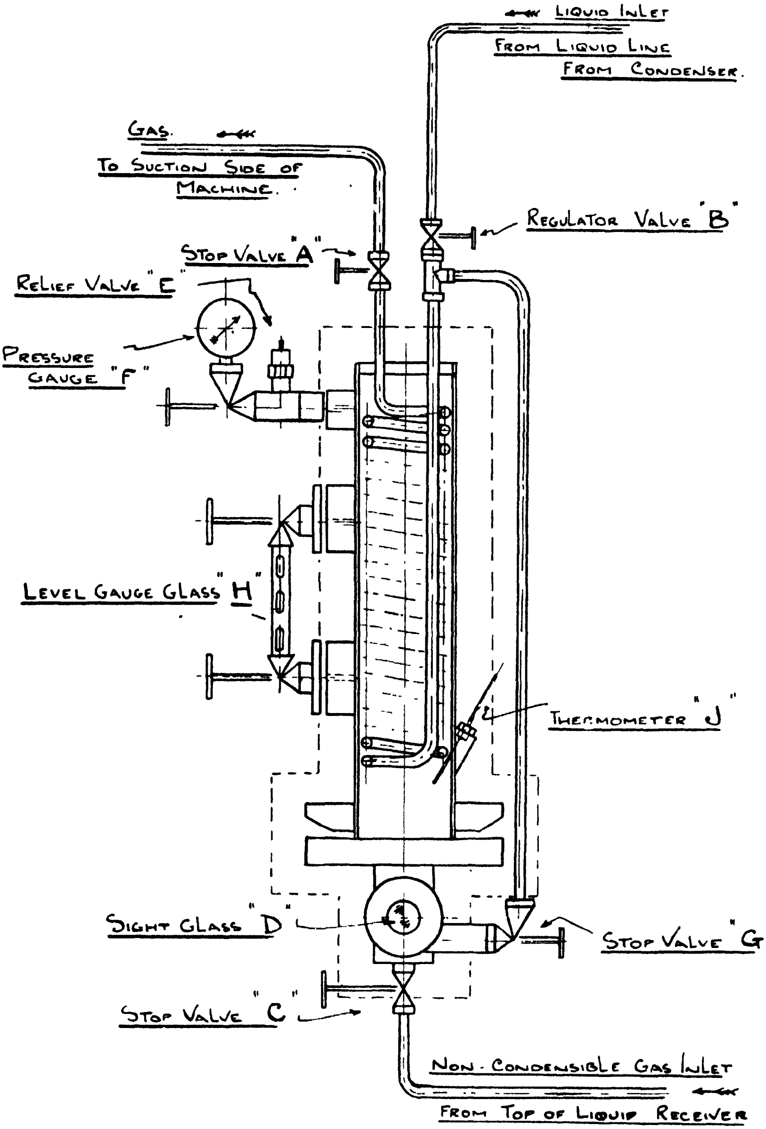

FIG. 72.—NON-CONDENSABLE GAS PURGER

The non-condensable gases rise and, when sufficient pressure is obtained, pass out through the relief valve. Ammonia liquid will continue to collect in the vessel until a level is reached half-way up the level gauge *H*. This liquid can then be utilized in the coil by opening the valve *G* slightly, at the same time closing the regulator *B* a little at a time until conditions are such that a frost line shows slightly beyond valve *A* on the compressor side of it. When once set, the action of the purger continues automatically, and it should be allowed to continue working until the system is purged of non-condensable gases, which will be indicated by no discharge at the relief valve *E*. Purging should then be stopped and resumed at intervals of a few hours until all non-condensable gases are expelled.

In other examples an alternative connection for drawing off non-condensable gases is provided to the ordinary purge valves at the top of the condenser, and the discharge pipe is usually immersed in water in a glass beaker so that the discharge can be observed.

Cleaning Condensers. To prevent corrosion and wasting of condenser pipe surfaces, they should be protected by a good rust-preventing bitumastic or other similar anti-fouling paint, and in order to get the best heat exchange the surfaces should be kept free from deposit.

The open type condensers are the easiest to keep clean and painted, and it is simple to maintain a constant inspection of their condition. At the same time regular inspection of the surfaces is most necessary with this type, for with the combined exposure to air and water corrosion of unprotected surfaces is far more rapid than with those which are constantly submerged. The distributing pipes or troughs should be regularly cleaned out and an even flow of water maintained over the coils.

Double-pipe condensers can be inspected by withdrawing the water return bends, and cleaned by passing through a wire brush or tube scraper if the deposit is of a hard nature.

Submerged condensers are more difficult to clean, as scale and mud are apt to collect on the coils, and its removal is difficult on account of the close nesting and inaccessibility of the coils. The casings can sometimes, with advantage, be washed out with a hose but the usual procedure is to remove and clean the coils. A method, said to have been used in the United States with some success, consists of putting a solution, consisting of one part of muriatic or hydrochloric acid to two parts of water, into the condenser casing and leaving it until effervescence ceases. After treatment the scale could be washed away as mud. During treatment a considerable quantity of gas is evolved. The same method is commonly employed for cleansing scale out of water pipes, etc.

When sea water is used the pipe coils should be galvanized externally, and galvanizing is often advisable with river waters, as it appears to prevent vegetable growth which is otherwise apt to form.

Liquid Receivers. A receiver or collecting vessel for the condensed liquid is generally supplied with an ammonia compression refrigerating plant, and its functions are—

(*a*) To provide a storage space for some ammonia in excess of that required to give the best working conditions in the condenser and evaporator ;

(*b*) To ensure a supply of liquid at the regulating valve and prevent any possibility of uncondensed gas passing through it ; and

(*c*) To provide storage space in the event of its being necessary to pump out any section of the plant to enable it to be opened up for repairs or extensions.

In small plants where the loss of a few pounds of ammonia might leave the machine distinctly undercharged, the first point is of special value. With a receiver many of these will run for several years before it is necessary to add any ammonia, and then the whole contents of a small drum can be added at one time. Without the receiver it would be necessary to add small amounts at more frequent intervals, and unless the drum was the property of the owner he would have to pay hire charges on it, or return it when he had only used a portion of its contents.

The receiver vessel should preferably be of the vertical type.

It should be fitted with a gauge glass above the liquid outlet, having valves which close automatically in the event of breakage of the glass. The liquid outlet should be some little way above the bottom and, at the bottom, there should be a valve through which any oil that passes the separator can be drained off at intervals. The oil, having a greater density than the liquid ammonia will, of course, tend to settle at the bottom of the receiver.

With evaporative condensers, the liquid receiver is frequently omitted. They are usually of sufficiently large capacity to provide all the excess storage space necessary, and as they are generally placed high up on a roof, there is a considerable head of liquid in the pipe leading from the condenser to the regulating valve or valves.

Liquid Coolers. The refrigerant liquefied in the condenser should be cooled to as low a temperature as possible by the ordinary water supply. The more heat that can be extracted from it before it passes the regulating valve the better, because it reduces the cooling, by partial evaporation, that occurs on the low pressure side of the regulating valve, and consequently increases the refrigerating effect of the remainder.

The cooling of the liquid is of particular value with CO_2 machines, for with CO_2 the self-cooling of the liquid prior to evaporation represents a greater proportion of the total heat of evaporation than with other refrigerants in general use.

In counter-current condensers such as the double-pipe, the submerged, and flooded types, this cooling is automatically effected as the liquid leaving is cooled by the cold water entering, but with the evaporative type condensers a separate liquid cooler, which may be of the double-pipe type, can generally be installed with advantage, the make-up water supply, which is always required, being taken from the main or the coldest source obtainable, and passed through the liquid cooler on its way to the condenser.

Evaporators. The evaporator, expansion, or low pressure side of a refrigerating plant varies in its character and arrangement to a considerably greater extent than any other portion.

It is in this section that the refrigeration is effected and applied. The compressor, condenser, and other parts only serve to re-compress and condense the ammonia or other agent so that it can be used over and over again.

A rough subdivision may be made into two general types—

(*a*) Evaporators used to cool brine which is, in turn, used as the cooling or refrigerating agent ; and

(*b*) Evaporator systems in which the cooling is effected directly by the refrigerant.

(*a*) Brine coolers are made of similar construction to ammonia condensers. The most usual form is the coil and tank type, constructed like the submerged condenser, and consisting of a number of continuous welded coils in which the refrigerant evaporates. The coils are closely nested together and contained in a tank through which the brine is passed. The inlet and outlet coil terminals are connected to suitable manifolds, the liquid inlet generally being at the bottom and the gas outlet at the top.

For ammonia, the construction is sometimes reversed, the ammonia being evaporated in the casing and the brine passed through the coils. This type is generally referred to as a shell cooler, Fig. 73. While circular coils are sometimes used this involves bolted covers and terminal glands subject to ammonia pressure. The general construction, therefore, is to use a welded vessel with straight tubes expanded into the end plates. The covers over the end plates are arranged like a surface steam condenser, to give the brine a number of passes through and thus obtain a high velocity and rate of heat transfer.

Brine coolers are often made of the double-pipe type, generally of 2 in. and 3 in. pipes. Occasionally these are submerged in a tank to gain the benefit of the cooling effect from the outer pipe surfaces. If the cooler is of the usual built-up type this, however, has the disadvantage of large numbers of submerged and inaccessible joints. Brine coolers are often of similar construction to open condensers and are then sometimes referred to as Baudelot coolers (*see* Fig. 147, p. 426). In

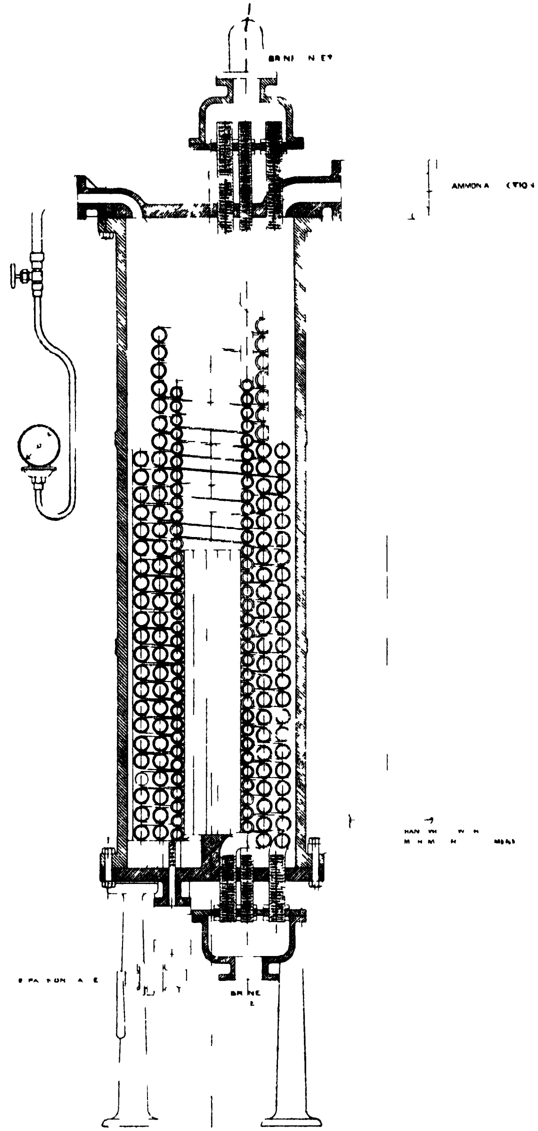

FIG 73

coil type brine coolers it is usual to allow from 90 to 100 ft. of 1 in. pipe or from 70 to 80 ft. of 1¼ in. pipe per ton refrigeration. In double-pipe and shell coolers it is usual to allow about 12 sq. ft. of surface per ton refrigeration, which is equivalent to about 20 ft. of 2 in. pipe.

(*b*) The refrigerating effect obtained directly by the evaporation of ammonia, CO_2, or other agent, is used for the cooling of insulated rooms and is then generally referred to as the direct expansion system. For air coolers where the air is blown over coils of piping, and when the temperature is below freezing-point, these are arranged to stand over a brine tank, and a circulation of brine is maintained over the outside surfaces of the piping to keep them free from frost.

In the Pluperfect system of ice-making tanks (*see* p. 279), and in some plate ice systems, direct expansion is employed and brine entirely omitted. This has also been done with milk coolers, with ice-cream freezers, and with other apparatus. The use of brine has, however, many advantages, as it acts as a cold accumulator. It may, in fact, be said to induce a fly-wheel effect, and when there is any variation in the load, it makes for simplicity and ease in regulation with a constant running condition. When there are many circuits to control, it is easier to adjust the flow of brine through these than the ammonia through a number of regulating valves working in parallel, and in many apparatus, such as milk coolers, the use of brine permits of a more suitable construction for the purpose for which the plant is required.

The Flooded System. In any evaporator system a portion of the liquid evaporates in passing the regulating valve and cools the remainder to the temperature corresponding to its pressure of evaporation; thus, taking the conditions for standard ton refrigeration rating, and assuming that the liquid is at the temperature of condensation, i.e. 86° F., some 16·1 per cent of the liquid must be evaporated in order to cool the remainder to the temperature of 5° F., at which its evaporation for refrigeration is effected.

The further heat required for evaporation is taken up from air, brine, or other fluid which the plant is arranged to cool, so that in a pipe system there is a mixture of gas and liquid, the proportion of liquid decreasing until, in dry compression, it is completely evaporated.

In brine coolers and in piping for ice tanks, when wet compression was general, there was a considerable diversity of opinion as to the merits of top and bottom feed, i.e. of admitting liquid from the regulation valves into the top or bottom of the coils.

With dry compression bottom feed became universal. but it was necessary to increase the pipe surfaces, as with the decreasing proportion of liquid the heat transfer decreased. The flooded system was introduced to obviate the necessity for this and to avoid expense, and though any evaporator actually contains a considerable proportion of liquid, it was --as its name implies- devised to enable the plant to run, as far as possible, with the evaporator system full of liquid.

With the flooded system working with coils, a vessel termed an accumulator is used, into which the ammonia passes from the regulating valve. This vessel has connections for the compressor suction pipe, the pipe for the gas outlet from the coils, and for the liquid feed to the coil inlets. It should be placed some few feet in height above the evaporator pipe coil system so that the liquid feed takes place by gravity. The gas formed by the partial evaporation involved in the cooling of the liquid and which, of course, effects no external refrigeration, passes direct to the compressor. The vessel also acts as a separator so that the entrained liquid in the suction gas is deposited there, and the gas passing on to the compressor is in a dry, or relatively dry, state.

A shell cooler, Fig. 73, is naturally worked in a flooded state without any external accumulator or separator vessel, the large surface for the evaporation of the liquid and the area above it ensuring that the gas leaving is dry or practically dry.

Cross Connections. Where two or more machines are installed they should be cross connected on the delivery and also on the suction sides, so that either compressor can work independently, or both together, on the condenser and evaporator systems, which should preferably be arranged in a similar number of units. This is exceedingly useful in cases where any section of the plant may have to be shut down for repair or in case of breakdown, and it is a necessity in cold storage plants constructed to pass Lloyd's Scale, the regulations for which are given in Chapter XI.

Valves and Fittings. To ensure strength and gas tightness with the high pressures used, the valves and fittings for CO_2 machines are generally machined from mild steel billets or, in the smaller sizes, from drop forgings. For ammonia the valves and fittings are generally made of semi-steel or a high quality, close-grained cast iron, and screwed fittings of malleable iron castings.

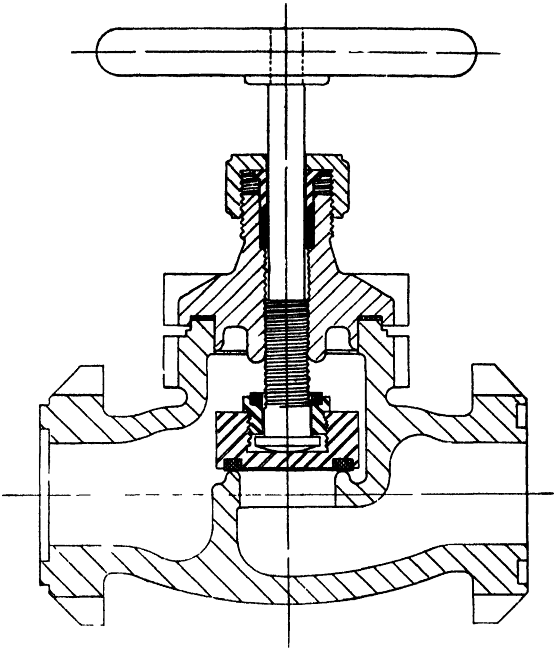

Fig. 74

The valve discs are generally made with a soft white-metal seating dovetailed into them. For ammonia it is usual and good practice to provide a seating on the upper side of the valve disc, as shown in section in Fig. 74,* which closes on to the underside of the valve cover or bonnet. This enables the valve spindle to be re-packed without loss of ammonia when the valve is wide open.

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* Messrs. L. Sterne & Co., Ltd., Glasgow.

On the evaporator side, as the valves are generally frosted over when the machine is working, the frequent melting off of the frost is apt to cause corrosion. To avoid this it is good modern practice to make the valve spindles of rustless steel.

The regulating valves should have a fine thread on the spindle, and the spindle should extend through the valve opening, either as a tapered cone or with a parallel portion in which a tapering slot has been made in order to give a very fine adjustment. The handwheel is often made with an index plate on the rim with a pointer attached to the body and adjoining it, as shown in Fig. 75. This is a great advantage to a relatively unskilled attendant, who, having once been shown, can, in running his plant, always get his valve setting without difficulty and with confidence to the point which gives the best, or approximately the best, condition of working for the particular plant in his charge.

The regulating valve should be used as a regulating valve only, and should not also have to serve as a stop valve. It is generally recommended that a stop valve should adjoin the regulating valve on the condenser side.

At one time cocks were largely used, but owing to the difficulty in turning them and their liability to jam up, their use has been entirely abandoned except by some makers for the smaller sizes.

The joints in CO_2 pipe systems are usually made with a copper ring placed between the ends of the pipe, which are faced square and then drawn up tight by heavy flanges screwed on to the pipe, but occasionally the Boyle joint is employed.

For ammonia, flanges are made either of the spigot and socket type, with a jointing ring of lead or compressed compound sheeting or the Boyle type of joint is employed.

With spigot and socket flanges, the flanges should be screwed and sweated on ; the flange is made with a recess at the back which is run up with solder, the pipe and inside of the recess being tinned.

Occasionally, when taper threads are used, the flanges are

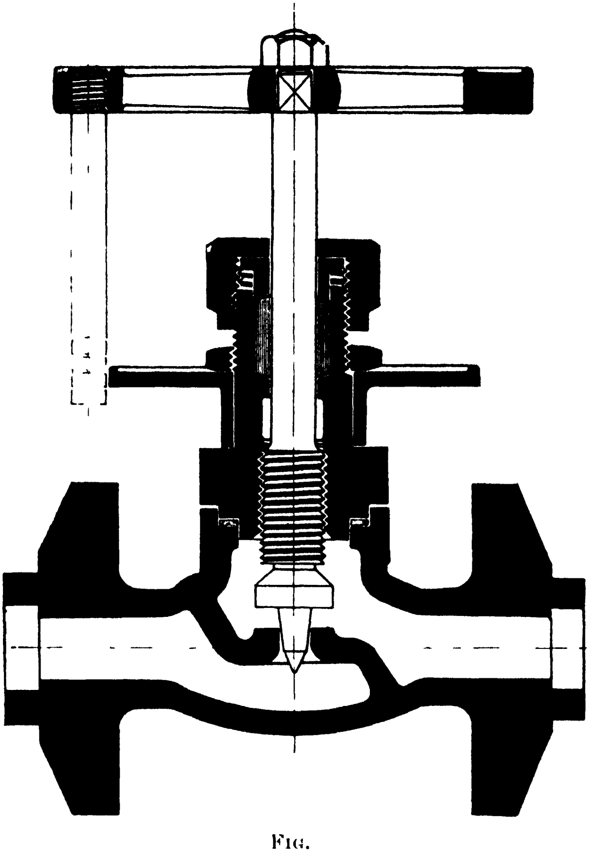

FIG.

screwed on to the pipe with a mixture of litharge and glycerine, but this practice cannot be generally recommended.

Fig. 76* illustrates a straight through valve, and Fig. 77* an angle valve, both for ammonia.

Dryers and Purifiers. A dryer is a very useful adjunct which is frequently omitted.

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* Messrs. Peter Brotherhood & Co., Ltd.

Water is not desirable in a refrigerating plant, and it is particularly objectionable in a CO_2 machine as it will freeze at the regulating valve, blocking it and completely upsetting the working. If that should occur it can be remedied by introducing some methylated spirit which will be dissolved in the water, forming a non-freezing solution that will be gradually discharged by the oil separator drain.

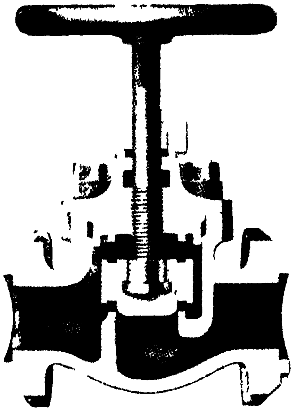

FIG. 76

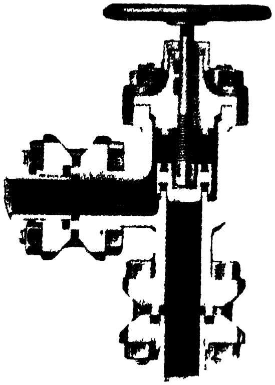

FIG. 77

A word of warning may be inserted here as to the danger of using naked lights near the separator drain, when it is open shortly after inserting any methylated spirit, as the discharge, when mixed with the air, will be an explosive one. Prevention is, however, better than cure, and whilst the CO_2 specially prepared and sold for refrigeration is strictly anhydrous there is, as a rule, an appreciable quantity of water in the cylinders of CO_2 sold for ordinary commercial purposes.

If there should be any doubt as to the dryness of the gas, it is advisable to hang the cylinders up, valve downwards, for a day or so before use and then, while in that position, to slightly open the valve and to blow out any accumulated water, and afterwards to charge the gas into the machine through a dryer filled with calcium chloride.

Ammonia has a great affinity for water, which can contain in solution at normal temperature some eight hundred times its own volume of the gas. Any water in an ammonia refrigerating machine is, therefore, in the form of aqua ammonia, such as is used in the absorption type of plant, and whilst this cannot cause any difficulty owing to freezing, its presence is undesirable.

An ammonia dryer and purifier can be installed with advantage in any large plant. It consists of a vessel placed in a by-pass on the suction pipe fitted with trays which, as a rule, are filled with calcium chloride and caustic soda. When it is necessary to re-charge with fresh materials, the vessel can easily be pumped out, the cover removed and replaced after re-filling, and the vessel put back into service again.

CO_2 Refrigerating Machines

A machine working with CO_2 was patented in 1881 by Raydt, and curiously enough Professor Linde, whose name is so well known in connection with ammonia machines, was one of the first, if not the first, to experiment with CO_2 as a refrigerating agent. One of the first really practical machines, however, was invented in 1886 by Windhausen of Berlin. The essential parts of the machine consist, like the ammonia compression machine, of a compressor, a condenser, a regulating or expansion valve, and an evaporator. There is, however, a wide difference in the details The relative behaviour of ammonia and CO_2 machines under different conditions has been fully gone into in Chapter II, and the results there obtained represent the theoretical advantages and disadvantages of the two agents.

The practical advantages and disadvantages are quite another matter. Reference to p. 4 will show that while the pressure in pounds per square inch of CO_2 at zero F. is 310, that of ammonia is 30, but that for an equal refrigerating effect the relative volume of the compressor necessary for the two substances is respectively 3·24 and 23·3. Thus, while ammonia vaporizes at a much lower pressure than CO_2, it requires a very much larger compressor area. These two points principally govern the design. The high pressure required is merely a mechanical effect, and can be easily and readily dealt with by mechanical means. Any disadvantages it may present are amply compensated for by the smallness of the necessary compressor area and the consequent saving in material and space.

The success of the system which was developed by Messrs. J. & E. Hall, Ltd., of Dartford, England, has caused other makers to place CO_2 machines on the market, and as with ammonia machines, design and practice have been stabilized.

On account of the high pressures to be dealt with, great soundness and strength of the various parts are essential. To meet this, the compressors are bored out of a solid steel forging, cast iron or cast steel being unsuitable on account of its porosity. This precaution is taken for the double purpose of securing a sound and reliable material, and of providing a perfectly smooth bore, as it is plain that any unevenness or inequalities in the cylinder would, with the pressures to be dealt with, be a very serious matter. The suction and delivery valves are all made to the same design and are interchangeable. The compressor piston, in modern practice, is usually packed with metallic packing.

The Condenser. The condenser is made of both the submerged and atmospheric type. Owing to the pressure, special hydraulic piping, usually of 13/16 bore, is employed, the lengths being electrically welded together, so as to minimize the number of joints generally, and to render it unnecessary to have any joints in an inaccessible position.

These condenser coils for land work are usually of wrought iron, but for marine work or for any special purpose the coils, both in the condenser and evaporator, are made of copper, either plain or tinned.

The Evaporator. The evaporator is, in general design, similar to the condenser. For cold storage work and ice making, separate brine coolers are almost invariably employed, as the pressure is too high to make direct expansion advisable on any extended scale. In this case the evaporating coils are nested one inside the other. In cold stores employing the air blast system the air is blown directly over brine coils in much the same way as that described in Chapter XII, or in some cases over larger metal surfaces wetted and consequently cooled by the cold brine from the evaporator.

General Considerations. It has frequently been urged that CO_2 machines cannot work successfully under conditions found in tropical and semi-tropical countries, where the temperature of the condensing water is high. This contention is discussed in Chapter II, and in this case theory is fully borne out by the results which have been obtained in practice. The compactness of the CO_2 machine makes it very suitable for work in positions where space is of especial value, such as, for instance, on board ship. The smallness of the charge and the working parts, and also the existence of the safety valve, render a serious explosion practically impossible. The harmlessness of the gas and the comparative smallness of the charge prevent any escape that may occur from having serious consequences.

For work with high temperature condensing water a gain in efficiency can be made by pre-cooling the liquid CO_2 before it passes to the regulating valve, and, as shown in Chapter V, this is resorted to by some makers.

The pre-cooling is effected by partial evaporation of the liquid at some convenient pressure and temperature between the pressures of condensation and evaporation. The compressor then actually works with two stages of compression. In the first stage it collects the vapour coming directly from the evaporator, and in the second stage there is added the gas formed by the partial evaporation of the liquid in the pre-cooling vessel.

Cylinders for NH_3 or CO_2. Owing to the occurrence of several explosions of cylinders containing compressed gas, a committee was appointed by the Government in 1895 to inquire into the whole matter. The committee duly presented an exhaustive and interesting report,* its recommendations as regards the above being as follows.

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* Parliamentary Papers C 7952—Committee on the Manufacture of Compressed Gas Cylinders. These do not apply to India. Further recommendations, applying particularly to gas cylinders for special purposes, are made in reports Nos. 3 and 4 issued by the Gas Cylinder Research Committee before its dissolution in 1929.

After setting forth the hydraulic and annealing tests, etc., to which the cylinders are to be subjected, it is stated that for CO_2 the maximum working pressure is to be reckoned as 120 atmospheres (1,800 lb. per sq. in.). All the cylinders are to be either of lap-welded wrought iron or steel, or of seamless steel, and each cylinder is to be clearly stamped with the tare of the cylinder and the greatest permissible weight of CO_2 it may contain. This latter is limited to $\frac{3}{4}$ lb. of CO_2 for each pound of water capacity for this country, and $\frac{2}{3}$ lb. of CO_2 per pound of water capacity for the tropics.

Before being sent out the cylinders are to be labelled, stating that they contain CO_2, and that they are to be kept in a cool place. If the cylinders are sent out unpacked, the valves are to be protected by a metal cap.

For NH_3 the same general recommendations apply, but the maximum working pressure is fixed at 1,000 lb. per sq. in., and each cylinder is, before being used, to be tested hydraulically to 1,500 lb. per sq. in. The cylinders are not to contain more than $\frac{1}{2}$ lb. of NH_3 per lb. of water capacity.

Generally it is recommended that each cylinder should be marked with a rotation number, a maker's or owner's mark, and an annealing and test mark with date; that tests should be repeated at intervals of two years, and annealing at intervals of four years.

It is the practice of Messrs. J. & E. Hall to fit each CO_2 cylinder with a safety valve so that no accident can possibly occur.

CHAPTER VII

AUXILIARY PLANT

Buying Machinery. It is presumed that the capitalist or business man who desires to buy machinery for producing a certain effect or carrying out a definite purpose, be it the production of power, refrigeration, or electric light, will confine himself and his knowledge to the results he wishes that machinery to give him ; that is to say, he will regard the machinery as only an indispensable accessory to his object, not the object itself. He will thus be in the position of wanting something done in order that he may do other things in which he is more particularly interested, and from which he hopes to attain monetary gain. Suppose, for instance, he is anxious to erect a cold store or an ice factory. His object in doing this will be the derivation of a profit from the storage of perishable articles or from the sale of ice. He will know that for both purposes refrigerating and other machinery is as indispensable as the buildings in which the plant is situated, but he will interest himself mainly in selling his ice and securing goods with which to fill his cold stores. These will be his chief care, and on them he will lavish his skill and business acumen. As it is not his business, he will probably know little or nothing about the details of the machinery he wishes to buy, but in order that his profits may be large he will desire that it shall be capable of cooling his stores, or making his ice, at as small a cost as possible. He will, however, recognize that the cheapness of an article depends on more things than price, and will clearly discriminate between expenditure on capital and revenue account, and, while endeavouring to keep the former within reasonable limits compatible with the provision of first class work, he will be anxious that the latter should be kept at a minimum. Having clearly made up his mind what he wants to do, he will turn his attention to the best means of doing it, and will adopt one of two courses. Either he will go to some manufacturer and himself obtain a quotation for the whole plant, give the orders, and attend to the details, or he will consult some independent expert in whom he has confidence, who must essentially be a good business man with a knowledge of the markets, and who will advise him and tell him how, having regard to all the circumstances, he can best and most cheaply attain the objects he has in view. In either case he will be guided by the advice he receives. The secret of buying machinery cheaply is to buy it individually, each machine from its own maker. The expert, if he is wise, will follow this course, and, after designing his arrangements and finding out definitely and exactly what results he wishes the machinery to give, will not attempt to design that machinery itself, but will draw his specifications, and call for competitive tenders, from the various manufacturers, for machinery of standard design in their respective works. In this specification, he might mention details which he would prefer to have if they could be obtained at a reasonable cost, but, at the same time, it should be clear that machinery of standard size and make is wanted, and that the non-provision of these details should not disqualify any contractor from tendering.

The manufacturer has devoted his time, experience, and money to finding out what design is, from every point of view. the best and most economical. He has made this his standard, and he has all the patterns and templates necessary for quickly making the various parts. He knows exactly what a machine of a certain standard size will cost him to make, and what results it will give under certain specified conditions. He also knows that his success depends on his making these standard machines and these results as good as, or better than, those of his competitors, and he is prepared to guarantee that they will do what he says. At one time the curse of the English engineering trade was the meddlesome way in which engineers who were buying machinery interfered with the makers' designs, and either insisted on having the machines built from their own design, or at least in specifying the leading dimensions. The result of this was that makers had to make, and the client to pay for, new designs and patterns for every machine ordered. The contractors never had a chance of standardizing their work, and consequently had to quote high prices and excessive time for delivery. It is a matter of comparative indifference to the business man in what way the details of his machinery are arranged, provided that it is fully capable of performing the work he requires of it, at least as economically in all respects as that made by any other maker. The expert should recognize this, and, while satisfying himself that he is getting what he wants and maintaining a general, and sometimes very necessary, supervision over the quality of the materials used and the workmanship employed in the manufacture of the machinery, he should devote himself and his experience to the general design of the plant and buildings, of which the machinery forms only a part, and with which the various manufacturers of the machinery have no concern.

The object of an expert is to save his client time and money, not to exercise his idiosyncrasies, and he cannot hope to do this unless he fits his plans to the use of machinery, the standard design of which is the very essence of its cheapness and efficiency.

Engines

A steam engine sometimes forms part of the refrigerating machine, and is supplied with it, each maker having his own standard. There is not much room, therefore, for choice apart from that of the refrigerating machine, for when the one is decided upon, so also to a great extent is the other. Great improvements have been made in the steam engine, and it is now, both in construction and efficiency, vastly superior to what it used to be. These improvements can be traced largely to the use of a high pressure steam, superheating, multiple expansion, and the use of condensers, as well as to improvements in valves and valve gear, the introduction of piston valves, drop valves, and Corliss, and other quick release trip valves. Constant and steady running has also been rendered possible by improvements in governing and methods of lubrication.

The principal points to be considered about the engine, as indeed about the whole machine, are –

Efficiency. By this is meant not merely efficiency under test, but continuously under ordinary working conditions. The engine should not require more than 14 lb. of steam per b.h.p. hour when working condensing, or 20 lb. when working non-condensing. These may be taken as outside limits for good work. Owing to the slow speed at which refrigerating machines, when combined with their own steam engines, usually run, the cylinder condensation is rather serious. This may be guarded against by jacketing the cylinders with live steam or superheating, and the majority of the best makers now follow this practice. Marine type engines require a greater quantity of steam per i.h.p.

Simplicity. The more simple the design of the engine the better, as an excessive number of working parts increases the attention and repairs required. The working parts should be easily accessible for examination when running and for repairs. Many a hot bearing would have been avoided had it been more easy to get at the working part. It is an advantage, too, for the main bearings to be so constructed that they can be got at, and the brasses taken out, without dismantling the machine.

Durability and Solidity. As refrigerating machines require to run day and night for long periods, solidity in construction is absolutely necessary. The bedplate and frames should be of massive design and well braced. The machine should be firmly bolted down, so that there need be no vibration when it is at work. The eyes and pins of all joints that are not fitted with brasses should be case hardened. Changes of section should be gradual, and corners should be rounded. The shafts and motion bars should be of high quality mild steel.

If the machines are of standard design, all the working parts should be made strictly to gauge and template, and should be numbered, so that in case of a breakdown it is only necessary, in order to obtain a duplicate part, to telegraph the number of the part broken to the makers. Similar working parts should be interchangeable from machine to machine. and spare brasses, etc., should be kept for emergencies. When it is remembered that thousands of pounds worth of goods are liable to be ruined if the engine breaks down and the temperatures rise, it will be seen that a few pounds spent in what are sometimes called refinements, but which enable repairs to be quickly and cheaply executed, are well invested.

Types of Engines. The design of a steam engine for direct driving a refrigerating compressor requires special knowledge of the characteristics of the latter. There are three methods of coupling in general use : (*a*) by belt drive ; (*b*) side by side , and (*c*) by coupling the compressor piston rod direct to an extension of the steam piston rod. They are sometimes built with the steam engine at one end, the compressor at the other, and the crank in the middle. This is known as the opposed type.

Each system has its own advantages, but it should always be remembered that the steam engine exerts its maximum effort at or near the beginning of a stroke, whereas the compressor requires it near the end of a stroke. For this reason the flywheel must be heavy, and the crankshaft and connecting rods of ample proportions to withstand the heavy work thrown upon them.

Uniflow Engines. In modern horizontal engines drop valves are mostly used, but a type of engine which has successfully been applied to refrigeration is the uniflow. This engine is fitted with drop valves for the steam inlet, but the exhaust is through ports in the cylinder walls, at the middle of the cylinder. The length of the piston is such that these exhaust ports are only uncovered at the ends of the stroke.

This type of engine is very economical on steam consumption, and with sizes between 100 and 200 h.p. using high steam pressure and superheat, a consumption less than 11·5 lb. per b.h.p. hour can be obtained. The uniflow engine can also be economically used to drive a dynamo for electrical distribution either by direct coupled or by belt driving.

Vertical High Speed Engines. Fig. 78* shows a vertical high speed triple expansion steam engine, direct coupled to a dynamo for electric driving.

For average conditions the steam consumption of a 600 b.h.p. engine of this type with steam at 150 lb. per sq. in. and 150° F. superheat, and when exhausting into a condenser, may be taken at about 13·5 lb. per b.h.p. hour.

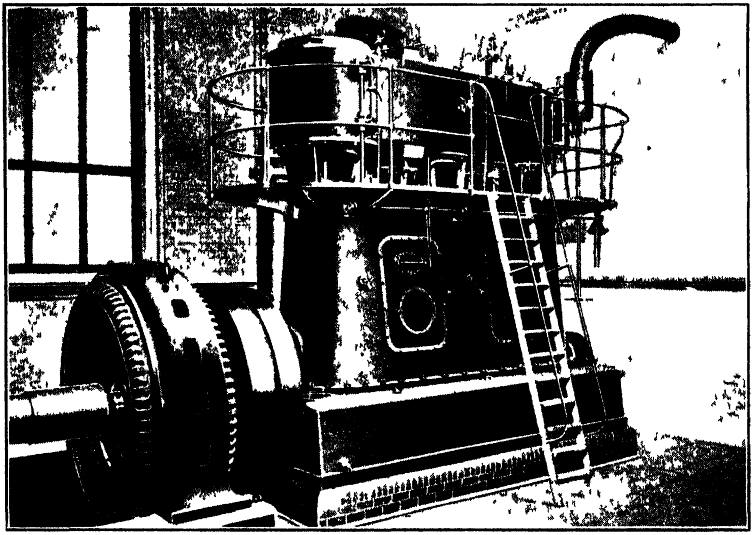

FIG. 78

Steam Turbines. For large installations where it is intended to drive all the refrigerating machinery electrically, and where there is an ample supply of water for condensing purposes, the steam turbine has many advantages over the reciprocating engine, the chief one being the smaller floor space occupied by a turbine as compared with an engine.

Steam Condensers. Engine condensers may be divided into two classes: (*a*) surface, (*b*) jet. There is not much to choose between them as regards efficiency. Jet condensers are cheaper in first cost, but care has to be taken to reduce the risk of the condensing water getting back into the engine cylinders. Surface condensers are nearly always used with turbines.

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* Messrs. James Howden & Co., Ltd., Glasgow.

Boilers and Steam Pipes

The selection of suitable boilers for cold storage and ice-making plants is, like that for other factories, largely a matter of convenience. Each particular form has its staunch advocates, and its claims are urged often quite irrespectively of the conditions under which it has to work. The types may be conveniently divided into three classes—

1. The Cornish and Lancashire boiler.
2. The marine, dryback and locomotive boiler.
3. The water-tube boiler.

The Cornish and Lancashire Boiler. These boilers are simple in construction and have ample internal space. They are easy to clean and examine, and, owing to the amount of water they contain, they possess great steaming capacity. For the same reason, and in order to avoid stressing the boiler too heavily by unequal expansion, steam should be raised very gradually. This, though a drawback in cases where the boilers are liable to meet heavy and unexpected demands on their steam, is not a matter of importance where the load remains as constant as it usually does in refrigerating work. The Lancashire boiler is merely a development of the Cornish type. The general principles are the same, but the former has two fire flues, while the latter has only one.

The use of Lancashire boilers for pressures over 160 lb. per sq. in. is not to be recommended as, owing to the thickness of the end plates, the furnace tubes cannot expand freely, with the result that grooving takes place and the gusset rivets soon begin to leak. Corrugated and other specially constructed flues are fitted to overcome this difficulty, but they are apt to give rise to other troubles.

In most modern boiler installations where the bulk of the steam is used for power purposes it is the practice to install superheaters, and these are fitted in the down take at the back end of the boiler.

The Marine, Dryback, and Locomotive Boiler. Though these boilers are sometimes put in where it is necessary to economize floor space, or where the water-tube boiler is for some reason or other objected to, they are not recommended except for small powers, as they are not economical and, owing to the large number of tubes, they are very difficult to clean and examine. This objection particularly applies to the locomotive type. With the dryback or marine type the saving in space is the great consideration.

The great fault with both Cornish, Lancashire, and marine boilers is the small grate area.

Water-tube Boiler. Water-tube boilers are more suitable than Lancashire boilers where steam has to be raised quickly and where high steam pressures are required. They can be built in larger units, have a very large grate area, and for heavy duties the floor space for a given output is less than for Lancashire boilers. One of the best known examples of the water-tube boiler is the Babcock.*

Steam Piping. The layout of the steam piping between the boilers and engines should receive particular care, especially as regards drainage and expansion. Solid drawn steel pipes only should be employed, and all pipes, including flanges and valves. should be efficiently lagged.

Fuel Economizers. In order to reduce the coal bill it is of importance to make use of as much of the heat of combustion as possible. This is the object of the economizer, which consists of a nest of tubes built into a by-pass flue, so that the hot gases on their way from the boiler to the shaft can pass around them. The feed-water is pumped through these tubes on its way to the boiler, and its temperature is raised, so that it enters the boiler at or near boiling point. The tubes are kept free from soot by scrapers actuated by a small steam engine or electric motor. Consideration of space, however, sometimes necessitates this useful apparatus being omitted. In some instances the flue gases are used to heat the air before it reaches the fire, and in large installations both economizers and air heaters are sometimes installed. Another type of feed-water heater makes use of the heat contained in the exhaust steam; these are well known and need not be described.

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* Messrs. Babcock & Wilcox, Ltd., London.

Besides utilizing heat which would otherwise go to waste, a feed-water heater is useful inasmuch as, by heating the water before it enters the boiler, lime and other substances held in solution are deposited in the heater instead of in the boiler, where they would form scale. This is dealt with more fully under the head of water softening.

Automatic Stokers. As a general rule it may be taken that automatic stokers are only commercially successful for heavy duties and with water-tube boilers. They are often fitted to Lancashire boilers, but owing to the small size of the flue tubes they do not give very good results. The type most generally used on water-tube boilers is the chain or travelling grate.

Oil Fuel. In congested areas oil firing is sometimes resorted to mainly for the reasons that oil is so easily handled, and that there are no ashes to dispose of. Fewer firemen are required, and these savings often amount to more than the extra cost of the fuel oil as compared with coal.

Water Softening. The use of hard water for boiler-feeding purposes involves losses, which can be classed under three headings—

1. Loss of efficiency owing to the formation of scale on the boiler tubes or plates.
2. Labour required to clean or chip off this scale.
3. Corrosion of boiler tubes and plates.

Most hard water can be easily dealt with by the ordinary lime and soda process. The plant for doing this consists of three main portions—

(*a*) The vessel in which the reagents (lime, soda, etc.) are mixed with water in the correct proportions.

(*b*) The measuring and mixing apparatus by means of which the correct quantity of mixed reagents is measured out and mixed with the in-coming hard water.

(*c*) A filter or filters to remove the precipitates thrown down by the reagents.

The water supplies in different districts of this country vary very considerably not only in the degree of hardness, but in the nature of the hardness, and it is necessary before installing a softening plant to make an analysis of the hard water and ascertain exactly what, and in what quantities, salts have to be removed or rendered harmless in the boiler. The action of the reagents is either to precipitate the salts causing the hardness, or else change their state so that they are soluble even after the water is heated.

Time, to a great extent, enters into the design of water softening plants, as with some waters it takes longer for the reagents to act than with others. It is a good plan, therefore, when installing a softening plant, to arrange for a storage of the softened water so that in the event of the demand varying these variations are not thrown back on the plant itself. This allows the softening plant to work at a steady rate.

Where it is desired to reduce the hardness of water to zero, the zeolytic filtration method can be employed. This system is somewhat more costly to use than the lime and soda process, but it is more cleanly in operation as there is no lime sludge to be dealt with. The hard water is passed over zeolyte or "Permutit," which removes all the temporary and permanent hardness, and when the action of the zeolyte is exhausted it can be restored by treatment with a solution of sodium chloride.

Condensing Water Cooling. A good supply of clean, cold water, such as is obtainable from a river, is a valuable asset to the cold store owner, as fairly large volumes are required for condensing for both the refrigerating as well as the steam plant. Where, however, such a supply is not available it is necessary to resort to some method of cooling the condensing water so that it can be used over and over again. This can be done with a cooling tower or, where ground space permits, by means of a cooling pond with spray jets. The principle of operation is the same in both cases, namely, the reduction of the sensible heat in the water by evaporation.

Internal Combustion Engines. When no steam for heating is required a very cheap method of producing power is by means of internal combustion engines. They can be classified according to the fuel used, and are as follows: (*a*) town's gas; (*b*) suction gas using anthracite or coke; (*c*) heavy residual oil; (*d*) refined kerosene.

(*a*) and (*d*) are not often used except for small installations, as the fuel costs are usually rather higher than (*b*) and (*c*). An installation of suction gas engines is shown in Fig. 100, facing p. 252. They are very economical power producers, particularly if the load is a steady one and the power is required twenty-four hours per day.

During the last few years many improvements have been made in the design of oil engines. The Diesel principle, i.e. "the firing of the charge entirely by the heat produced by compression of air," is generally used on larger engines, but the smaller sizes are usually of the type known as "Semi-Diesel." In this engine a lower compression pressure is used and a portion of the cylinder is left uncovered by the water jacket. Oil is sprayed into the cylinder at, or near, the point of maximum compression, and the hot bulb fires the charge. The fuel oil used is known as Diesel oil, which is crude oil from which some, but not all, of the lighter oils have been removed by distillation.

Some engine makers claim that their engines will work satisfactorily on the cheaper residual or tar oils, but it should be remembered that the cost of cleaning and overhauling the engine will be higher, and it is doubtful if any actual saving will be made.

Fig. 79* illustrates a crude oil engine which will start from cold. The first impulses are given by compressed air; this is then cut off and kerosene or refined oil is fed to the engine for a few minutes. It is then changed over to the residual fuel oil it has to run on. There is an impulse every cycle of four strokes at all loads, the amount of fuel oil being regulated by the governor. The engines are built from 18 h.p. upwards, the larger sizes being twin engines handed and coupled. The fuel consumption of this type of engine is very low. An engine of 100 constant working brake horse-power (125 b.h.p.

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* Messrs. Tangyes, Ltd., Birmingham.

maximum) will, for instance, only require at full working load 0·425, at half load 0·452, and at quarter load 0·583 lb. of fuel oil per brake horse-power. The fuel oil to give these results must, of course, be of average quality with a heating value of 18,000 B.T.U. per lb., and a specific gravity of from 0·8 to 0·9. Under these conditions the engine will work satisfactorily on any Diesel type fuel oil of commerce. There are, of course, many makes of oil engine on the market which will give results comparable with the one illustrated, which is intended to illustrate a type particularly well suited for driving a refrigerating machine.

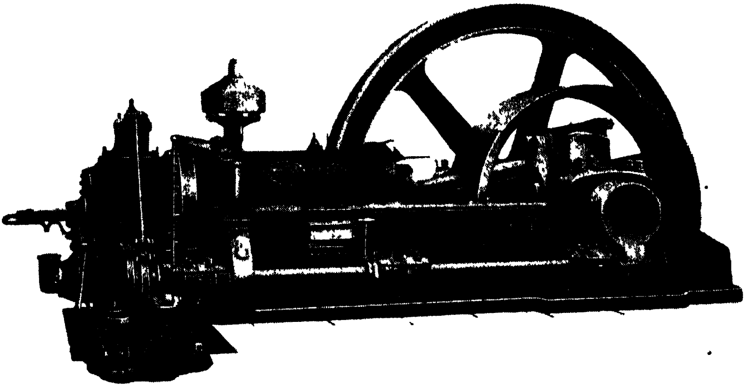

Fig 79

Wells. A supply of clean water is necessary for ice making, and unless this can be obtained cheaply from the public supply it will be necessary to sink a well, the depth depending upon local conditions. This may either be of the " dug " or " borehole " type, the latter usually being cheaper for deep wells. When the water is within 20 ft. of the ground almost any form of pump can be used, but for deep boreholes either air lift or a single barrel deep well pump is necessary. An air lift is very simple as there are only pipes in the well, all machinery being placed above ground, but they are expensive to operate. For a dug well either a three-throw or centrifugal pump can be installed, the driving gear in both cases being at the ground level.

Circulating Pumps. For brine and water circulation the centrifugal pump direct coupled to an electric motor makes the best arrangement. For these duties a large volume at a small head is usually required, and these are the conditions under which a centrifugal pump is most efficient.

Positive acting pumps for circulating purposes should be fitted with pressure relief valves on the delivery side, but this is not necessary with centrifugal pumps as the delivery connecton of the latter can be closed entirely without any harm resulting.

Boiler Feed Pumps. In deciding upon the proper size of pump to install for boiler feed purposes, the amount of water the boiler is capable of evaporating, not the horse-power of the engine, should be taken as a basis, and the pump should be large enough to comfortably supply this. Duplex direct-acting pumps are frequently used for the boiler feed, and though they use a large amount of steam they work well.

The Weir boiler feed pump has a positive valve gear and will start working immediately steam is turned on. The pump runs at the slow speed of 12 double strokes per minute, and the valve gear ensures full length of stroke and constant action. Steam is used expansively, and as the piston automatically slows down towards the end of the stroke, there is no shock or jar. and the valves are enabled to settle quietly on their seats.

Air Lift Pumps. The air lift pump consists of two plain pipes which are let down into the well. The pipes are connected at the bottom into a bell-mouthed piece as shown in the diagrammatic illustration, Fig. 80. The outer pipe contains the air, and the inner one is the delivery pipe for the water. There are no valves of any description except, of course, in the steam engine and air compressor, and as no standing water remains in the pipe when not at work, there is no danger from frost. When working, air, in excess of the pressure due to the head of water in the well, is forced down the outer pipe into the mouthpiece ; from this point the air

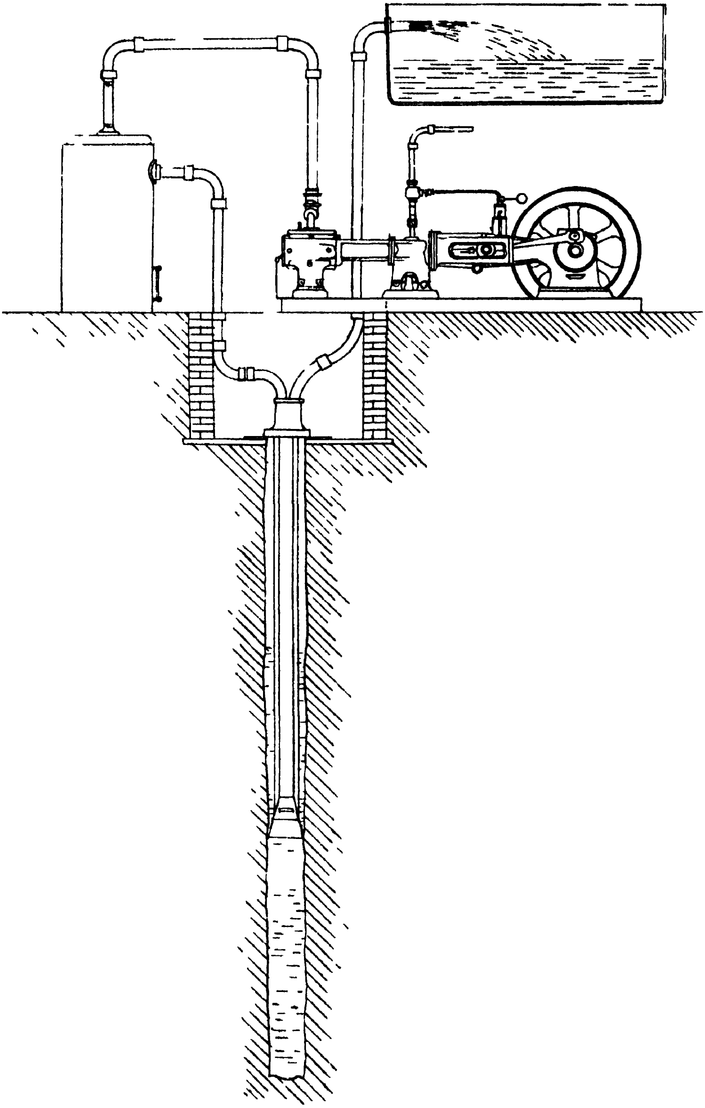

Fig. 80

rises in the delivery pipe, and, forming air pistons, carries the water with it to the surface. The pressure of the column of air and water in the delivery pipe being less than that of the solid column of water outside the water flows continuously to the surface. As the air pistons rise in the delivery pipe, they expand in direct proportion as the load upon them becomes lighter, and, when discharged, they are at atmospheric pressure. A simple illustration of the action of these air bubbles can be seen in any soda water syphon just as it empties. The gas forms air pistons in the central glass tube, and they carry up the soda water with them, expanding as they rise. The expansion of the air when doing work has a remarkable cooling effect on the water raised, a result which is all gain when the water is used for condensing purposes. The air compressor may be situated at any distance from the well, and is, as a matter of fact, usually placed in the engine room with the other machinery.

Before installing these pumps it is necessary to obtain the fullest possible information of any capacity test to which the well has been subjected, and especially the differences in the levels of the water which have occurred while any particular amount of water is being pumped from it.

Those methods of calculation which have given the best results in practice are as follows. The first thing to do is to ascertain the level at which the water will stand in the well while pumping is in progress. Supposing, for instance, a well has a static water level of 60 ft., and when, say, 5,000 gallons per hour are being pumped, this level drops to 100 ft. from the surface ; under these circumstances it is necessary, in order to obtain sufficient submersion of piping, to double the head of 100 and add from 10 to 20 ft. The bell-mouthed uptake pipe would then be 210 to 220 ft. from the surface. This will require an air pressure of about 100 lb. on the sq. in., and will secure a continuous and satisfactory flow of water. It is usual, on account of the head necessary before the pump will work, to only deliver the water to the surface, any additional pumping that is required being done by another pump of the ordinary type ; but if it is essential, for any reason, that the pump should deliver to a point above the surface of the well, this extra head must be included in the head to be pumped against and doubled accordingly. For lifting the water against a head of about 50 ft., 2 cu. ft. of free air per minute is necessary for each cubic foot of water raised; for a head of 100 ft., 3 cu. ft.; for a head of 150 ft., 4½ cu. ft.; and for a head of 200 ft., 6 to 7 cu. ft. is allowed. Assuming, therefore, that 5,000 gallons per hour are being raised 100 ft., an air compressor delivering 40 cu. ft. of air per minute would be necessary, or, as it is always desirable to allow a margin, a slightly larger size than this should be installed. As the air, even when it is delivered to the well just as it comes hot from the compressor, cools the water some 10 to 12° below its initial temperature, it is probable that if the air were first cooled down to atmospheric temperature by artificial means, the water in the well would be cooled considerably lower still. The size of pipe selected is one that will give the least possible friction to the flow of water passing through it. The capacity of the pump is practically unlimited, and with a properly proportioned plant it works efficiently up to sizes of 30 in. diameter, and is commonly used in sugar factories for lifting the beet from the flumes to the washers; considerable power is, however, required.

Electric Power and Lighting. It is hardly necessary to point out the advantages of electricity for power purposes in connection with cold storage. They are so great that most cold stores, particularly those situated in town areas where land is dear and electricity usually cheap, are driven entirely by electricity taken from the public supply. Even where a cheap public electricity supply is not available it will often be cheaper and more convenient for the cold store owner to generate all his power at one point, and to drive all the machinery, including the compressors, by electric motors.

So far as lighting is concerned, there is no other practical alternative to electricity, as electric lamps are the only means of lighting the cold rooms without introducing products of combustion. When a public supply of electricity is available, the question arises as to whether it is cheaper to buy the power or to generate it on the premises. The saving in capital cost is usually a powerful factor in any decision reached, and the whole question should be carefully gone into by a fully qualified engineer.

For large loads it is usual for the consumer to buy his electricity on the load factor system, and an agreement is made for a number of years between the supply company and the consumer. A fixed annual charge is made for every kilowatt or kilo-volt-ampere of maximum demand, to which is added a figure per unit consumed. This latter figure is usually subject to adjustment according to the price of coal. By this system the average price per unit works out lowest when the consumer's load is a perfectly steady one for twenty-four hours per day. The refrigerating compressor load is ideal in this respect, but some of the auxiliaries (lifts and hoists) used in a cold store are bad.

Where the electricity supply is alternating current it is usual to insert in the agreement a clause which penalizes the consumer if the power factor of his load falls below a certain figure. There are several methods of improving the power factor of an installation and the best ones are described later.

Reliability of the electricity is of the greatest importance, and all electricity agreements should, in fairness to the user, contain a clause penalizing the supply company in the event of a breakdown lasting more than, say, three hours. It is very seldom indeed that a stoppage of a supply lasts more than an hour or so, but it can easily be imagined how serious a loss a prolonged stoppage would be.

When it is decided to generate all the power on the premises there is a choice between direct and alternating current, and this to a certain extent is influenced by the particular type of prime mover. If the power is considerable, and a steam turbine is selected, then undoubtedly three-phase alternating current is the better alternative, as the alternator can be direct coupled to the high speed turbine. Direct current dynamos can be driven from high speed turbines through reduction gearing, but it is doubtful whether there is much advantage in this, as alternating current motors can be successfully applied to all the loads met with in cold storage plants. The only point where direct current has a distinct advantage is that, if necessary, a battery of accumulators can be installed to deal with light loads, and so enable the main generating plant to be shut down when the compressors are not running.

Three-phase induction motors are considerably cheaper than direct current motors, power for power, and as the former have no commutators they require less attention. Alternating current motors will also stand more rough usage than direct current, and this is a very important point to bear in mind when specifying electrical machinery which is operating under the conditions sometimes found.

When there is any choice of voltage it is best to keep this fairly low, particularly for the lighting circuits, on account of the general dampness in the stores when " thawing off."

Motors. Care must be taken that the motors should have the correct characteristics for their loads. The fields of direct current motors can be wound in three ways, viz., shunt, series, and compound. A shunt wound motor will run at a fairly constant speed from no load to full load, whilst the speed of a series wound motor will rise or fall according to whether the load is decreased or increased. At low speeds a series wound motor will exert a very large torque, and it is for these reasons that they are used for cranes and similar duties. A compound wound motor has both a series and shunt winding and combines the characteristics of both machines.

Refrigerating compressors require a fairly large torque to start them, but when the speed is up to normal it should remain reasonably constant, and a compound wound motor is most suitable for this duty.

Alternating current induction motors have very similar characteristics to shunt wound direct current motors. The starting torque is fairly good when slip rings are fitted, but with squirrel cage rotors the starting torque is poor. Squirrel cage motors are very robust and as they have no brushes they require very little attention. They are very well adapted for small powers, particularly for circulating pumps, small fans, etc., where the starting effort is very light.

A type of alternating current motor which has deservedly come into fairly extensive use is the auto-synchronous motor. One of the chief drawbacks to the induction motor is that it reduces the power factor of an installation particularly at low loads, but with the auto-synchronous motor the power factor can be kept high, and under certain circumstances it can also be used to correct the low power factor due to other motors on the circuit. Its appearance and construction are generally similar to an induction motor, but it is fitted with a direct current exciter which is so connected to the motor rotor that the motor will run in exact synchronism with the alternating current supply. This motor requires no special skill in starting, as it will automatically pull itself into synchronism with the supply frequency, and even if it should drop out of step owing to a very sudden heavy load, no harm can result. Particular care, however, is required in the design of this motor when it has to work on a load involving a periodic variation of torque, such as is met with in refrigerating compressors. An illustration of an auto-synchronous motor driving a refrigerating compressor is given in Fig. 81.*

Power Factor Improvement. There are several methods of improving the power factor of an alternating current installation, and when the plant is a new one there is no doubt that the best method is by using auto-synchronous motors. Another very satisfactory method, particularly where induction motors already exist and an extra motor is not required, is to use static condensers. They consist of a number of small condenser units coupled together and enclosed in a tank of oil. They require practically no attention, having no working parts.

Motor Starters. The motor starters and other switch gear used on refrigerating plants should be carefully chosen, as they often have to be operated by semi-skilled men. For this reason starters for large motors should be of the "foolproof" type, so that if any mistake is made by the attendant at any

* Messrs. Crompton Parkinson, Ltd., Chelmsford.

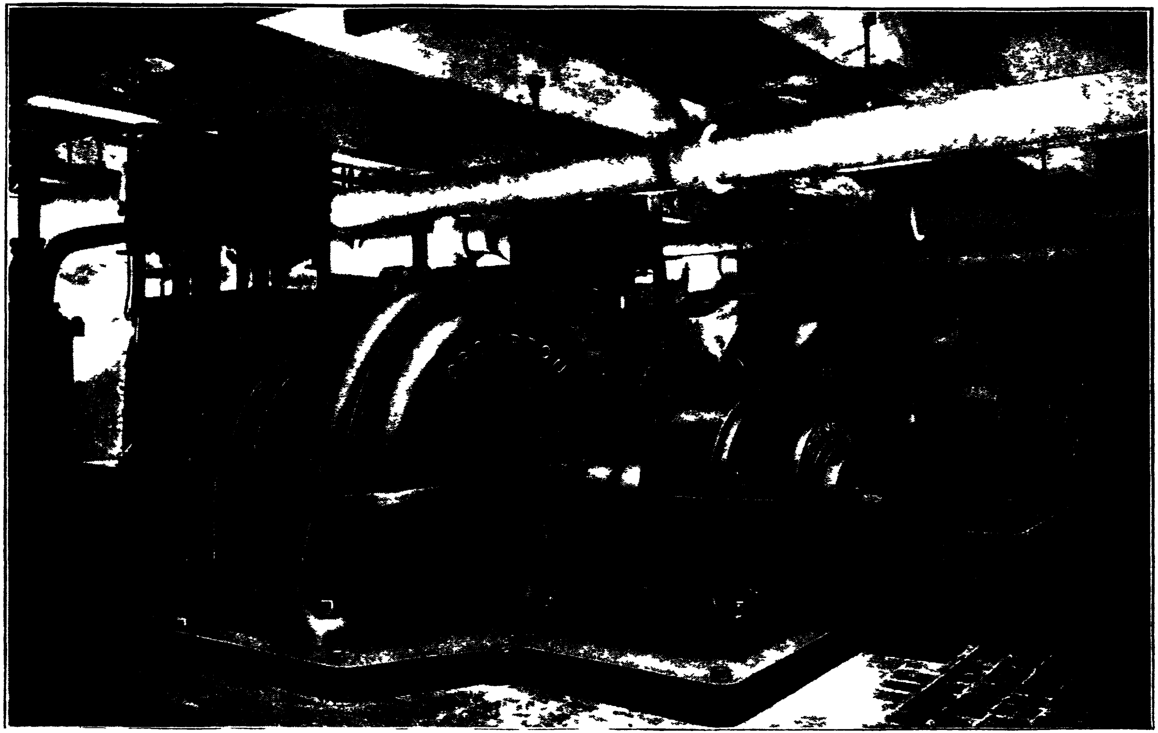

FIG 81

time during the starting period, the current will be automatically switched off and it can only be switched on again

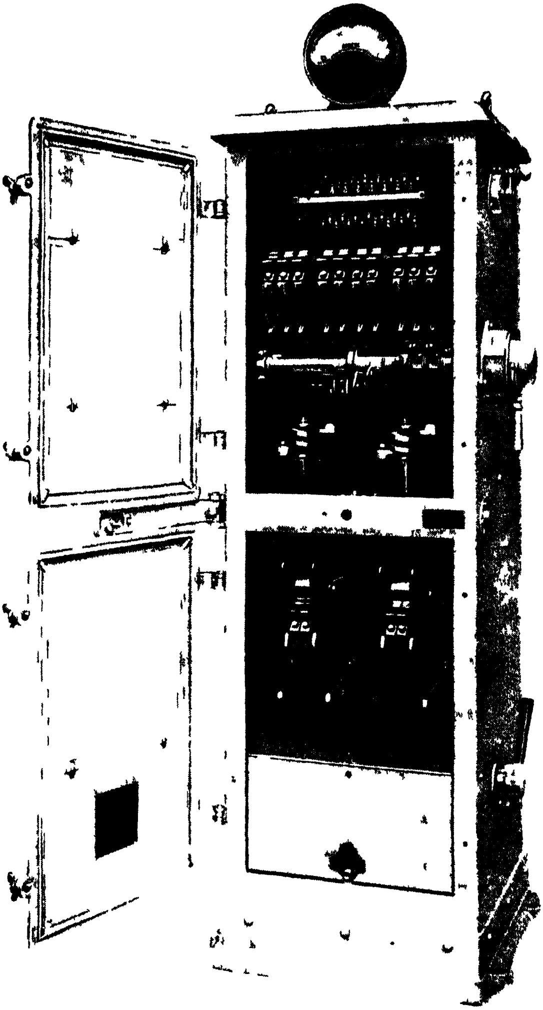

FIG. 82

by the attendant commencing the sequence of operations over again. It is a great help to the attendant if an ammeter is fitted to each starter, particularly in the case of centrifugal pumps when the starter is fitted with a shunt regulator.

One of the best types of direct current starters for heavy currents is the multiple lever pattern—as illustrated in Fig. 82.* This starter is hand operated and the rate of acceleration is under the control of the attendant. Fully automatic starters which are operated by push button are sometimes installed, but they are more expensive than the hand operated type. The starters for alternating current are usually somewhat simpler than for direct current, and Fig. 83† illustrates a type generally employed. This starter is push button operated, and it controls both the stator and rotor circuits. It embodies the usual safety features and interlocks. and the overload trips are of the " thermal " type.

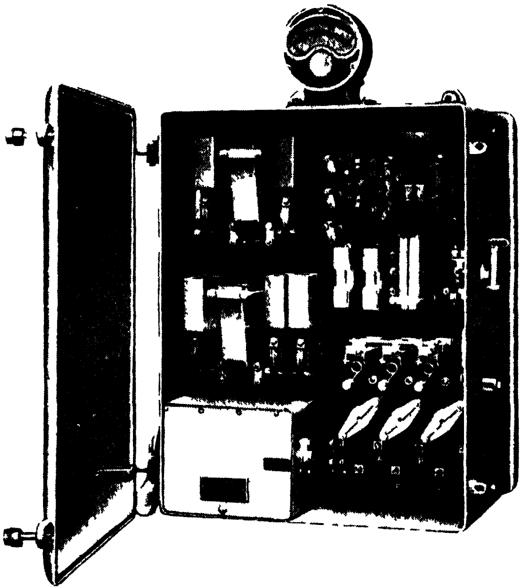

Fig 83

Small alternating current motors can, under certain circumstances, be switched direct on to the power supply lines, and they only require fuses for protection.

With a low speed refrigerating compressor it is always necessary to have some form of speed reduction gear when driving electrically, and probably the most satisfactory arrangement is a belt or rope drive.

Small machines are sometimes driven through spur gearing or chains, but these are apt to be noisy and they do not possess the flexibility of a belt.

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* Messrs Brookhirst Switchgear, Ltd , Chester

† *Ibid.*

Now that satisfactory high speed compressors are being made, as illustrated in Chapter V, direct coupling is possible, and a very compact arrangement of plant is the result. The best method of direct coupling is that which is generally used in connection with high speed steam engines and dynamos, where the armature or rotor is fitted with a half coupling which is bolted direct to the flywheel. With this arrangement it is advisable to mount the motor on an extension of the compressor bed plate, so that the set can be lined up at the maker's works before dispatch.

Electric Lighting and Wiring. It is desirable to cut down as much as possible the number of lamps in the cold rooms, as all the heat introduced by the lighting has to be removed by the refrigerating plant. When arranging the switches it is always a good plan to keep them outside the entrance of each room, with a master switch and small red pilot lamp, so that the engineer can see at a glance if all the lights in the rooms are on or off. The lamps require protecting against damp and mechanical damage, and ship fittings fulfil these requirements if fitted with heavy guards.

Electric light wiring in cold stores requires special consideration on account of the damp, particularly when the temperature of a room is allowed to rise for any reason. Steel tubing is quite useless, as with the changes of temperature condensation takes place inside the tubes and the rubber insulation soon perishes. Sometimes wood casing is employed, but this is very unsatisfactory and unsafe. The only method which will give good results is to enclose the wiring in a sheathing of metal or composition which will keep out the wet, and at the same time leave no air space between the cables and the sheathing. If lead is used it should be pure and not alloyed for the sake of hardness. It has been found that some of the lead-covered systems of wiring, where lead alloys are used, do not last under cold storage conditions, and this is due to electrolytic corrosion of the sheathing in the presence of moisture. The ends of the lead-covered cables should be sealed to prevent moisture creeping in and breaking down the insulation.

There is a class of cable which has a layer of hard rubber known as "cab-tyre," which has proved very satisfactory in use. It must be remembered, however, that with the lead-covered and cab-tyre cable the mechanical protection is poor as compared with steel tubing.

With a little scheming the majority of the wiring can be run in out-of-the-way positions, such as on the ceilings and in corners where it is practically impossible to come to any harm. Occasionally, however, it is necessary to run the wires in positions where there is a risk of their being damaged. It is only necessary in such positions to fit sheet steel guards over them.

It is of the greatest importance to see that all the lead sheathing throughout an installation is electrically bonded together and definitely earthed at a suitable point. If this is not done corrosion of the sheathing is liable to occur, besides adding considerably to the risk of fire and shocks.

Open type wiring, i.e. rubber insulated cables supported on porcelain cleats, is occasionally used, but it is a system which cannot be recommended except for cheapness.

As a cold store in the British Isles comes under the Factory Act, it is necessary to comply with the electricity regulations drawn up by the Home Office. In order to assist those responsible for electrical installations in factories the Home Office have issued a memorandum by the electrical inspector of factories on these regulations (Form No. 928, published by H.M. Stationery Office), and a careful study of this memorandum should always be made before an electrical specification is drawn up. Although these regulations have been in force since 1908, it is surprising how often they are ignored, with the result that expensive alterations have afterwards to be made.

Electric Lifts. It is modern practice to operate all lifts by electric power, as the running costs are usually cheaper than hydraulic power, although the latter is nearly always cheaper in first cost. Either alternating or direct current can be used, and the winding gear can be fitted either at the top or the bottom of the lift well. The former is to be preferred as the ropes are shorter, and with a well designed sheave drive the ropes only have one bend to make and that is over a large diameter sheave.

The best form of cage is the "through" type, i.e. with gates at opposite sides, but this is a point which has to be settled by the layout of the building. On no account should gates be fitted on adjacent sides of the cage, as with this arrangement it is difficult to stiffen the cage satisfactorily, and the guides and balance weights are awkward to arrange. Round or tee steel guides make for smooth running, although timber is quite satisfactory. A very good arrangement is to have steel guides mounted upon timber backings, the latter being fitted to take the safety cams of the cage. There are several types of safety devices, but they practically all take the form of cams which can grip the guides (or their backings) in the event of the ropes breaking or stretching unduly, the only real difference being the method of operation. The cams are sometimes connected to the lifting ropes in such a way that if any one rope breaks or stretches unduly, the cams are forced into the guides or backings by a weighted lever or spring. Another system employs a rope, one end of which is fastened to the cams, and the other end, after passing over a pulley or pulleys at the top of the shaft, is fastened to the balance weight. This rope normally carries no weight, but in the event of a failure of the load ropes a tension is applied, which pulls in the cams and arrests the fall of the cage.

One advantage of the electric lift is that it is a very simple matter to fit locks to the gates which are electrically interlocked with the control gear, so that the cage cannot be moved unless all the gates are properly closed, and that no gate can be opened unless the cage is opposite to it. The most usual form of lift control is by a switch placed in the cage. This is the best form where a regular attendant is employed, but if the lift has to be operated by different people a push button control can be installed. With this type of control, which however requires more maintenance, the switching off of the current is done automatically, and the cage floor stops level with the landing, thus making it easier to load or unload the trucks.

As the weights handled on a cold store lift are usually large, it is best to install a fairly low speed lift, say about 120 ft. per minute. The time taken in actual travelling is longer, but it must be remembered that most of the time required to handle goods into or out of a cold store is taken up in stacking or trucking, and that a few extra seconds occupied by the lift journey makes little difference to the total time.

General Uses of Electricity. There are many other purposes to which electricity can be put in cold stores beside lighting and power, the more common ones being telephones, bells and indicators, office heating, etc. In large stores or on board ship it is a great convenience to install electrically operated thermometers, so that the engineer or manager can see the temperature of any room on an instrument fixed in the engine room or office. These instruments are usually worked on the Wheatstone bridge principle by the variations of electrical resistance of a coil due to temperature change.

CHAPTER VIII

INSULATION

The Objects of Insulation. Space, enclosed by walls which have been well insulated, can be readily reduced in temperature and easily kept cool. The more carefully and effectually the heat is excluded, the smaller will be the consumption of power, and the greater will be the returns on the capital invested. For this reason the insulation, like the machinery, should be looked upon as a permanent investment. The expenditure is made once and for all, while the flow of heat which, in the absence of good insulation, will take place, is continuous and unceasing. It is not desired or intended to recommend that first cost should be lost sight of, or that unduly *elaborate* precautions should be taken to keep out the heat. A study of nature and her laws will show that, as a rule, the more simple the expedients adopted, the more likely they are to be successful. Frequently large sums of money have been expended in some costly and complicated arrangement of insulation, the result of which is not nearly so efficient as a more simple and cheaper arrangement of the same materials would have been.

The whole question is one of capital account versus revenue account. If the insulation is scanty, the sum on which dividends have to be paid is smaller, but in order to keep the necessary temperatures, so many extra tons of refrigeration and consequent cost of power besides oil, stores, and labour are required each year and reduce the amount available for dividends. If the insulation is good the capital is greater, but the working charges are less by the value of power, etc., saved. The problem to be considered, therefore, is how much money can be saved per annum on revenue account by spending a definite extra sum of money on capital account, and this is probably the most important point which comes under the engineer's consideration.

The flow of heat through any substance is proportional to the difference in degrees between the temperature on the two sides of that substance or, in other words, to the temperature head. There is no substance known which will absolutely stop the flow of heat and, therefore, the matter becomes one of degree.

Various Insulators and Filling Materials. For preventing conduction and convection of heat from one surface to another, still air is the best material that Nature has placed at the engineer's disposal. This statement does not hold good as regards radiant heat, but as that seldom comes into account and can be guarded against in other ways, it is not very material. Unfortunately, air if left to itself will not remain still but will circulate in currents, and so carry heat by convection. It is consequently necessary, in order to make use of the insulating properties of air, to find some means of preventing this circulation. The best insulating substance, therefore, is that which, for a given weight and volume, will contain the largest quantity of air in the most minutely subdivided particles. There are several substances which fulfil this condition to a greater or less degree of perfection, and they have been adopted as insulators or fillers in connection with refrigerating work. The most prominent of these, given in alphabetical order, are charcoal, cork, sawdust and shavings from hard and soft wood, and silicate cotton or slag wool. Other materials, such as hair felt, cow hair, rice husks, silicated straw boards, calcined pumice stone, red fibre, sanitary mattress (curled and dyed) have been experimented with, but as they are not in general use it is hardly necessary to refer to them in detail. Sawdust is familiar ; the principal characteristics of the others are as follows.

Charcoal. Wood charcoal is an impure form of amorphous carbon and, in addition to a small quantity of oxygen and hydrogen, contains a considerable portion of mineral matter. It is obtained by heating wood in the absence of air. There are in general use two kinds of charcoal—that made from shavings, turnings, etc., and that made from the carbonization of small pieces of wood not specially prepared.

Charcoal, while being inodorous in itself, possesses the power of absorbing gases and odours to a considerable degree. which makes it exceedingly valuable as a filtering material. It is exceedingly porous, and it contains a great quantity of air in minutely subdivided particles. It is to this property that it owes its high position as an insulator. Flake charcoal, once largely employed for this purpose, is manufactured from wood turnings, birchwood being principally used. The shavings are carbonized in mechanically fed retorts, and the charcoal is afterwards cooled by a special process which ensures that it will take up sufficient oxygen to avoid its subsequent reheating.

When sent out by the manufacturer the best quality flake charcoal weighs about 10 lb. to the cu. ft., and is packed into the insulation to a density of from 12 to 13 lb. per cu. ft. If subject to vibration, charcoal will settle down to a still greater density. This settlement can be remedied in a simple manner by removing the top boarding of the insulation and filling in the vacant space with new material. When first put in place the charcoal is filled in between the timber casings, and is consolidated either by being rammed down with sharp-pointed sticks or by vibration caused by hammering the containing woodwork. The former method results in tighter packing. but is apt to break up the flakes and cause powdering. By the latter method the charcoal is not packed quite so tightly, but it escapes damage and gives at least as good an insulation with smaller weight of material. Charcoal has no effect on metal, and can be packed directly against a ship's side or a steel bulkhead or girder without damage either to itself or the metal. Except in special cases, charcoal is little used in modern insulation.

Cork. Cork is produced from the bark of the cork tree, a variety of the oak family indigenous to, and largely cultivated in, Spain, Portugal, and other countries of the Mediterranean region. The peculiar formation of the bark is due to a natural process which, when expressed in botanical language, appears too alarming to be stated here. The result, however, is the formation of successive layers of cork cells which are filled with air. The tree—which lives to a great age—is first stripped of its bark at the age of from 10 to 15 years; this is virgin cork, and is useless for anything but what are alleged to be ornamental purposes. Every subsequent seven years the tree is again stripped. The curved strips are flattened by weights when under water and are charred or steamed to close the pores. For this latter purpose the bark is placed in large copper boilers.

Granulated cork, with which refrigerating people are more intimately concerned, is a by-product, and is made from the shavings and chips produced in the making of corks, as well as from the commoner qualities of cork wood. To produce it the chips, etc., are ground in ordinary grinding mills, care being taken to free the fibre from the bark, which is very gritty, and from the belly. It is then sifted or screened to separate the various sizes of grain, the coarsest and medium sizes being most commonly used for insulating purposes.

As an insulator cork is very valuable. It is exceedingly light, and it packs naturally to about 5 lb. to the cu. ft. In order, however, to prevent silting, it is desirable to pack it to a density of about 6 lb. to the cu. ft.

Cork Boards. Granulated cork is made up into slab form, which is by far the most useful, by subjecting it, simultaneously, to pressure and to a heat of some 700° F. This is done in moulds by hydraulic pressure, and produces slabs of regular size and of sufficient mechanical strength to enable the insulation to be built up in the same way as a brick or slab wall.

The natural gum in the cork is driven out under the action of the heat, acts as a binder, and causes cohesion of the granules. The slabs are occasionally impregnated with bitumen during manufacture, but there appears to be little advantage in this for ordinary purposes, and it causes a distinct reduction in the insulating value.

The cork slabs are usually erected with cement mortar or with bitumen as shown in Fig. 126, p. 330. They can, of course, be laid directly on floors and require no fixing; but for walls and ceilings, if already built, it is advisable in addition to the cement or bitumen to nail the first course to the walls or ceiling, and to secure the second and any succeeding courses to the first by means of ordinary hard wood skewers or long wire nails driven well home.

The great advantages of the slab construction are that timber can be largely eliminated. The cork floors can be covered as shown in Fig. 84 with asphalt, but if this is done it is best to give the slabs a thin coating of cement wash to prevent the hot asphalt charring the cork. They can also be covered with a granolithic flooring laid on top of concrete as shown in Fig. 85. Walls and ceilings are finished with hard setting waterproof cement.

The pressure used to compress the cork into slabs reduces the interstices between the granules, and consequently compressed cork is less liable to take up moisture than any other commercial insulator. This natural quality in the insulation is assisted by the fact that each slab is sealed in place by the cement or bitumen used for putting it up.

Two further points in its favour are that being in the form of sealed slabs no settlement of material, such as only too often occurs with loose fillings, can take place, and it does not harbour vermin as does granulated cork or sawdust.

It will be seen by the test figures given that there is relatively little difference in the transfer of heat through cork slabs and the other materials generally used. Owing, however, to the advantages enumerated, it is usually considered sufficient to use about one-third less total thickness. Thus 4 in. of cork slab would be employed where 5 to 6 in of silicate cotton would be required—or 6 in. of cork slab could be used in place of 8 or 9 in. of silicate cotton or granulated cork. The reduced thickness gives an increased capacity in a building of equal size. Insulation constructed of cork slabs is fire resisting, for though the slabs will char very slowly, they will not burn. If erected on brick or concrete, laid in cement mortar and finished on the room side with cement, cork is looked upon as a fireproof material by the Fire Office Committee, and is passed as such.

In erecting slabs in place care should be taken that the various courses break joint with one another in both directions.

Silicate Cotton. Under the various names of rock cotton,

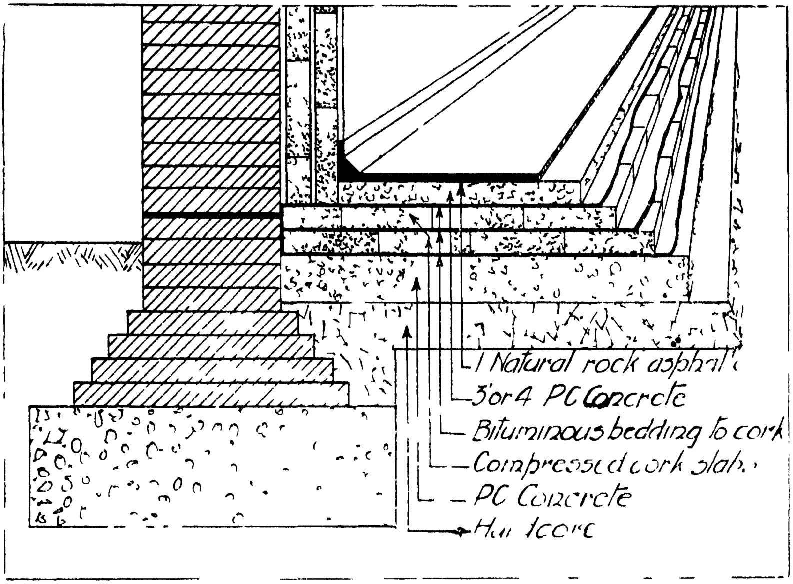
1 Natural rock asphalt
3 or 4 PC Concrete
Bituminous bedding to cork
Compressed cork slab
PC Concrete
Hardcore

FIG. 84

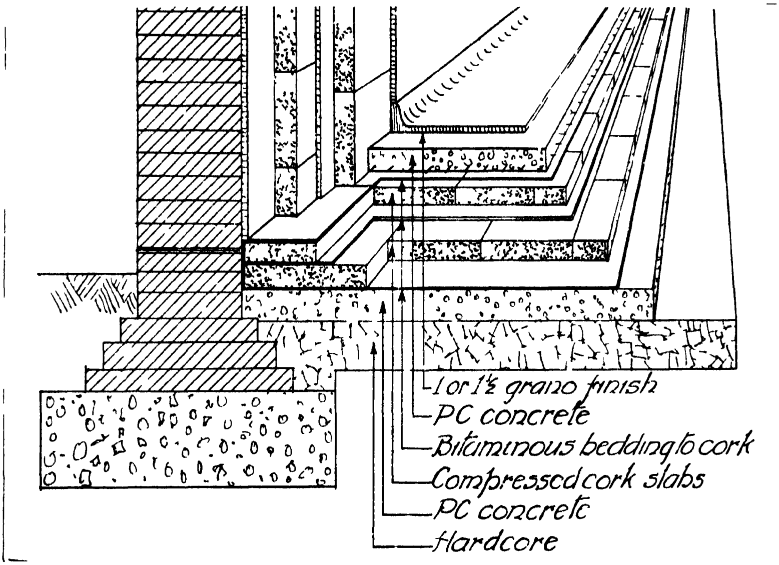
1 or 1½ grano finish
PC concrete
Bituminous bedding to cork
Compressed cork slabs
PC concrete
Hardcore

FIG. 85

slag wool, granite rock wool, etc., silicate cotton has been known for years and has, by merit, gradually forced its way to the front as an insulating material. It is a mineral fibre of the nature of spun glass, made from the slag of the blast furnaces. Granite rock cotton is made from crushed granite mixed with a small proportion of limestone.

The process of manufacture of silicate cotton was, it is believed, discovered by John Player, of Stockton-on-Tees, in the later 'sixties, and in 1870 he patented a process for the manufacture of the material. Silicate cotton should not contain much lime or it will become brittle and liable to pulverize. For this reason cotton made from a furnace slag, which is moderately free from lime, is the better. In the process of manufacture molten slag or granite and lime is allowed to flow from the cupola through an orifice, where it comes in contact with a high pressure steam jet which disintegrates it and blows it into a soft mass of fleecy fibres. These are mixed up and intertangled with each other, thus imprisoning a large amount of air in and between the interlaced fibres. The temperature of manufacture is about 3,000° F., and 1 cu. ft. of rock or slag will make about 12 cu. ft. of the finished material. As it is entirely a mineral product, it is not in any way liable to be attacked by, or attractive to. vermin, and it will not harbour animal life. Its insulating properties are considerably damaged if it gets wet, but as this applies to all other filling materials, and as, if paper is properly used in erecting the insulation, dampness will not occur, it is a point to which no material comparative importance need be attached. A great recommendation to the use of silicate cotton is the fact that it is absolutely fireproof, and - and this is most important -it is entirely without smell and will not absorb odours. Complaint has at times been made that silicate cotton, when used as a filling material, will settle in the insulation, and leave blank air spaces through which heat can pass both by conduction and radiation. There is, of course, some foundation for this charge, but it has probably arisen from the workmen having carelessly packed the wool too loosely. If packed to its proper density, 16 lb. to the cu. ft.,* the tendency to settle is not great, especially when it is remembered that the slag wool is in itself light, and that it has the skin friction of the studs and the match boarding on both sides to hold it up. Even if settlement does take place, after a few years the top of the insulation can be opened easily and the space, left empty by settlement, filled with new wool.

Slagbestos.† This is a preparation of slag wool, which is waterproof and will not absorb moisture from the atmosphere or by capillary attraction. Its value as an insulator or filling material is considerably enhanced, as, of course, slag wool which is wet is a bad insulator and is the best possible medium for encouraging rot in the timber which contains it.

Principles to be Observed. The qualities of good insulation may be enumerated as follows—

1. It should have a high specific heat.
2. It should be light in weight, free from unpleasant odours in itself, and a non-absorbent of external odours.
3. It should be non-hygroscopic, and should not hold moisture in suspension.
4. It should have no attraction for vermin.
5. It should not be liable to spontaneous combustion or contain acids liable to attack metals.
6. It should not be liable to decay or to settle after it is put in place.
7. It should present an airtight surface on the side exposed to the high temperature or source of heat, and an insulated layer on the inside.

Though these requirements at first sight appear to demand perfection, they can nevertheless be easily and economically met by a judicious use of the materials at command.

The efficiency of insulation should not be considered, as it often is, as depending solely upon the facility with which certain materials can resist the passage of heat. It depends also, to a very large degree, upon the construction of the insulation as regards the external walls, and way in which the insulator is put up. The heat that enters the building comes in chiefly by conduction through the materials forming the wall. The balance comes in by convection and radiation by and through the air. Heat is more easily conducted by a wet body than by a dry one, therefore the insulation should be absolutely dry. In order to convey heat air must move, therefore the insulation should be absolutely airtight. These two principles are the Alpha and Omega of good insulation, and no matter how it is varied in other particulars they should remain unaltered.

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* The researches of the Food Investigation Board have shown that, as regards insulating properties, there is very little gain in various densities over 10 lb. per cu. ft. For other reasons the figure of 16 lb. is considered best.

† Messrs. F. McNeil & Co., Ltd., London.

Air Spaces. In early American practice a considerable use was made of air spaces, the cold storage insulation frequently consisting of a number of boarded partitions closely spaced together to form a series of air spaces. This practice is now entirely discarded, and it is realized that the subdivision of the air must be exceedingly minute.

Air spaces are sometimes used in this country between the inside of the brick wall of the building and the inside layer of match boarding, the idea being to keep the timber away from the wall so as to lessen the chances of its becoming damped by any moisture coming through the wall. This was a very usual construction, and as the air space in the best designs is not more than ¾ in., or, if the grounds are brandered, 1½ to 2 in. wide, it serves a useful purpose. In fact, it is a case of convenience and cheapness versus theoretical efficiency. The insulation must be fixed to something and, owing to the number required, wood bricks are not satisfactory things to which to fix matchboarding. With this construction there is an undoubted advantage in brandering the grounds, and so reducing the area of the insulation proper which is in direct contact with the brickwork.

In more recent designs the walls have been covered with ruberoid or similar material, secured with mastic at the joints and the grounds fixed over it, as shown in Fig. 86. This, if properly carried out, ensures an absolutely damp-proof and airtight construction.

While it has been determined that better insulating value is obtained by filling in void spaces with a suitable insulating material rather than by leaving them as air spaces, the value

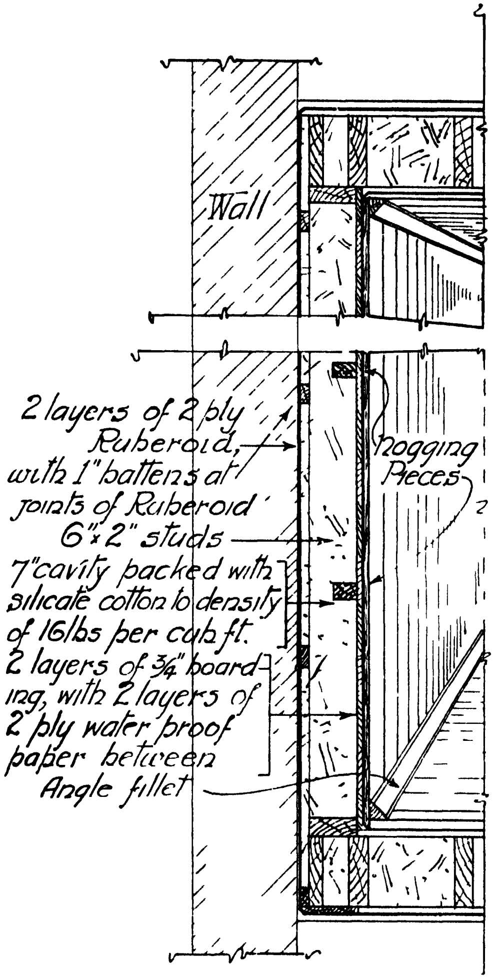
Wall
2 layers of 2 ply Ruberoid, with 1" battens at joints of Ruberoid
6"x2" studs
7" cavity packed with silicate cotton to density of 16lbs per cub ft.
2 layers of ¾" boarding, with 2 layers of 2 ply water proof paper between
Angle fillet
Nogging Pieces

Fig 86

of an air space as a constructional feature for the purpose of keeping insulation dry often arises, particularly with regard to air spaces in brick walls.

The following extract is taken from an article by the author which appeared in *Cold Storage** of as long ago as 15th July, 1901, and is perfectly true to-day—

> It is, of course, well known that air spaces in the brickwork are used to keep the damp out of dwelling houses, especially where the wall of the building is in contact, on its outer side, with the earth, such, for example, as in a cellar, and that in this position air spaces achieve to a greater or less extent their object. It is also well known that with a high temperature difference an air space is useful as a non-conductor, prominent examples being its use as an insulator between the cast iron of a steam cylinder and the planished iron lagging, or between the firebrick lining and ordinary brickwork of a furnace chimney shaft. Now, as regards dampness, a cold store is a building of the warehouse class, and, broadly speaking, only differs from an ordinary warehouse in certain details of its construction, and in the fact that a low temperature is required inside it, for which purpose it is insulated. In an ordinary warehouse there is no danger of the percolation of damp through the walls above ground level, especially if the brickwork is built in cement; and it is generally held that in such buildings air spaces in the brickwork do no good, but only add to the expense and weaken the walls—in short, it is not common or good practice to provide them. If, then, the walls of an ordinary warehouse will keep dry without an air space, and this is a fact beyond dispute, why not those of a cold store? If the wall is below ground level, the case is different, and there is a likelihood, not only of the percolation of damp, but also of water. In this latter case an air space will lessen, but will not prevent, the evil, and it is necessary either to provide a vertical asphalt damp course with a brick holding-up wall, or to provide an extra 4½ in. of brickwork, which is bounded into the rest of the wall but laid in hot asphalt, thus effectually preventing the ingress of both damp and water.

The old maxim of "keeping one's powder dry" is a very necessary one for the cold store owner of to-day, when applied to his insulation.

The characteristics which make good insulating materials also cause them to be distinctly hygroscopic, and if they become damp or sodden they very largely lose their value; the rate of transmission of heat being probably increased by at least 50 per cent.

As has been explained, cork slabs on account of their structure and methods of erection are less liable to damage from moisture than loose fillings. Of the loose fillings, granulated cork is probably the least susceptible, owing to the fact that the granules contain large numbers of minute and sealed air cells, whereas with other materials the subdivision of the air is to a greater extent caused by the material forming large numbers of minute and more or less connected interspaces.

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* *Cold Storage and Ice Trades Review*

In old cold storage rooms it is not at all uncommon to see ice on the walls and icicles hanging from the ceilings, and on opening up the insulation to find that portions are practically solid ice, or if the room has been out of commission a wet and sodden mass.

Moisture can obtain access to the insulation from both the inside and from the outside of the cold room. Inside the rooms, particularly in chill rooms, there is apt to be a drip from the pipes, and, in some cases possibly, a deposit of moisture from the goods. This should be carefully guarded against by, in all cases, constructing the floors with a waterproof finish and by fixing guttering with proper drainage beneath all piping in rooms which are only to be cooled to temperatures above the freezing point.

From the outside moisture may obtain access by percolating through the ceilings or containing walls, though, of course, the construction should be such that the direct passage of water is out of the question.

It is also necessary that the outer casing or wall should, as far as possible, be airtight. If air can percolate through the wall and into the insulation it will naturally be cooled there, and when cooled will deposit a portion of its moisture ; the progress of damage in this way is, of course, slow, but it is continuous and must be guarded against. It is good practice therefore, if rubberoid cannot be used, to coat all walls against which insulating materials are packed with a good bitumastic solution.

Paper. To ensure this condition of air tightness with timber construction and loose fillings, a specially made paper of considerable tensile strength, and impregnated with suitable chemicals which render it both air and moisture proof, is placed between two layers of match boarding on one or either sides of the filling material. The insulating properties, *per se*, of paper are not great. It is a very cheap substance, and is particularly useful in keeping out moisture and preventing the leakage of air. Plain brown paper which has been sometimes used is of no benefit whatever, as it is neither airtight nor moisture proof, the two essential properties. Paper for use in insulation should be entirely without smell, waterproof, airtight, strong enough to bear handling without tearing and, of course, of a lasting quality. When erected it should be laid in double layers, breaking joint into each other, between two thicknesses of match boarding. Particular care must be taken with the corners of the rooms and the junctions of the floors and walls, and the paper should be carefully fixed and the joints lapped. Too much trouble cannot be taken with this material, as upon its being perfect depends to a very large degree the success of the insulation. It should always be close laid between timbers. It is not advisable to lay it only on laths as is sometimes done, or stretch it between studs or joists with timber support on one side only, though this is preferable to its omission.

An objection sometimes made against the use of paper is that by isolating woodwork from the air it makes a condition favourable to the development of dry rot. The instances in which dry rot has occurred can only be a small proportion of the total of cases in which paper has been used in a similar way, and the rot would therefore appear to be more probably due to the use of timber which was not perfectly sound.

Dry Rot. In all refrigerating work one of the most important, and up to the present one of the most neglected, matters is the selection of the timber used in insulation, and the means which are taken to prevent its premature decay. Though insulation on land is for many reasons not so susceptible to decay as insulation on board ship, there is no doubt that it is susceptible, and in some positions deterioration is extremely rapid. This deterioration usually assumes the form of dry rot, which takes the nature out of the timber and renders it brittle and useless. It is only comparatively recently that the causes of decay in timber have been correctly understood. It used to be held that it was of the nature of oxidization, in much the same manner as rust in iron. This theory, however, neglects the organic nature of timber, and has been quite abandoned in favour of the ascertained fact that the decay is due to the action of living organisms which feed on the various constituent portions of the timber, some on one and some on another. The softer timbers, used in insulation, whose constituent parts contain the largest proportion of the common food—the cellulose—of the more malignant microbes, are the most prone to attack, and consequently suffer most largely. Robbed of its constituent parts the nature of the wood is changed. It, in fact, ceases to be wood, and becomes merely a collection of organic matter. In any cold store it is very difficult entirely to guard against the presence of humidity, and therefore in order to prevent decay it is necessary to treat the timber with some odourless substance which is toxic to bacteria, and will render the timber immune from their attacks.* When placing insulation in positions particularly susceptible to humidity, it is good practice to use a treatment of this sort. It costs many thousands of pounds to insulate a large cold store, and the author has known cases where, due to the presence of moisture, the insulation has had to be entirely removed and reinstated five to eight years after it had been installed. In addition to this there is the constant loss of refrigerating effect, due to the insulation being damp, and therefore inefficient. If by the expenditure of a moderate amount of money in treating the timber, which is most liable to get damp, the effective life of the insulation may be increased from eight to say twenty years, or even longer, it is surely worth it, and therefore the question becomes one of first class importance.

Outer Walls. The outer wall of a building which is to be insulated should be considered merely as a water and airproof shell to contain the insulation which is to be erected inside it. Its value as insulation is usually very small, and can generally be neglected, though in some special cases, where buildings with very thick walls are utilized, the insulating value of the walls might be taken into consideration.

The general construction of the insulation has been described

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* See p. 325, "Timber Construction."

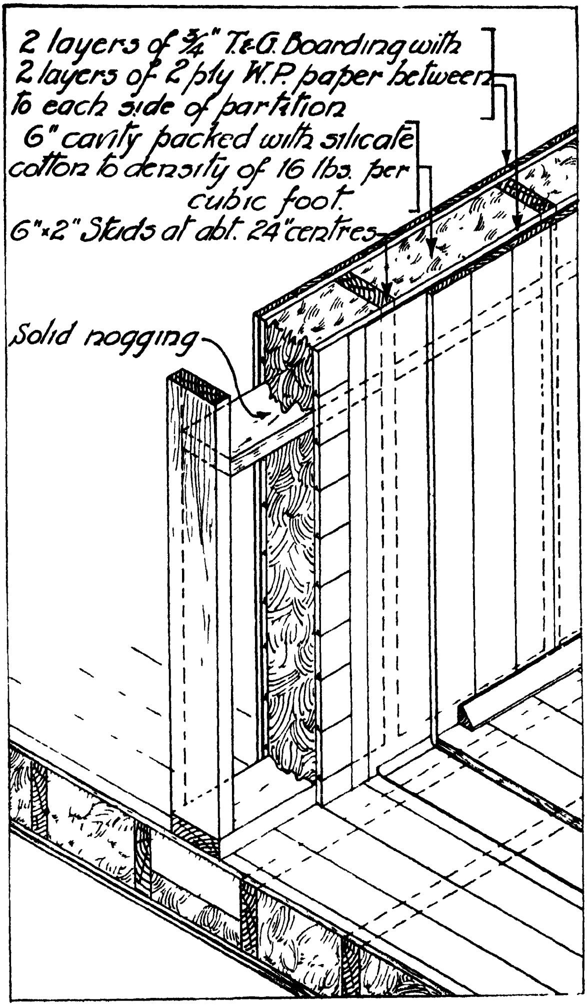
2 layers of ¾" T.&G. Boarding with
2 layers of 2 ply W.P. paper between
to each side of partition
6" cavity packed with silicate
cotton to density of 16 lbs. per
cubic foot.
6"×2" Studs at abt. 24" centres
Solid nogging

FIG. 87

in the preceding pages, and various examples are given in the following diagrams.

Partitions. Partitions and floors between walls need only be relatively lightly insulated, for although different temperatures may be required in adjoining rooms the actual difference will be small and the rate of transference of heat from one room to another, even through a thin insulation, will be relatively low.

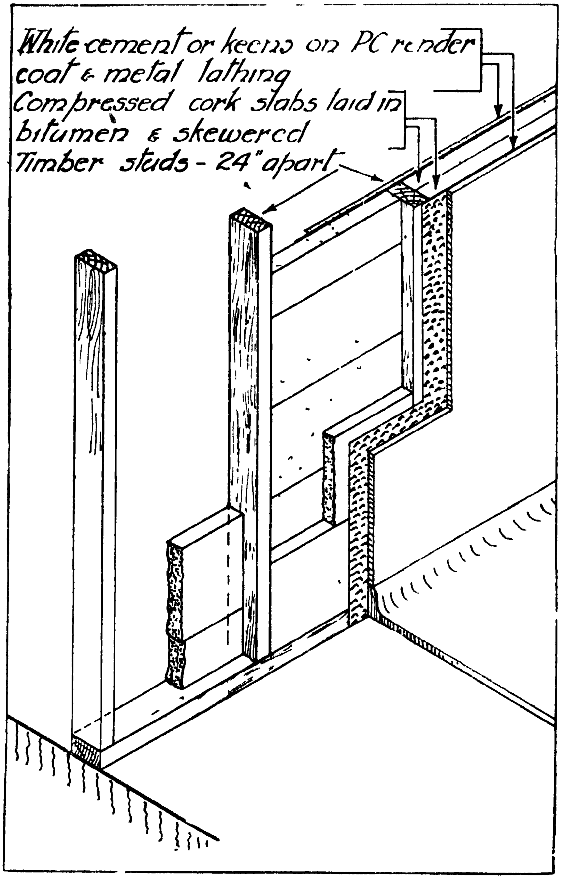
White cement or keens on PC render coat & metal lathing
Compressed cork slabs laid in bitumen & skewered
Timber studs - 24" apart

FIG 88

The insulation of partitions follows generally the same lines as that of the external walls, and the thickness is usually governed by the thickness of the studs necessary to make the partition wall a self-supporting and stable structure, the spaces between the studs being filled with the insulating material employed, as shown in Fig. 87. If the partitions are constructed of cork slabs, it is advisable to employ timber studding, to secure structural strength, as shown in Fig. 88.

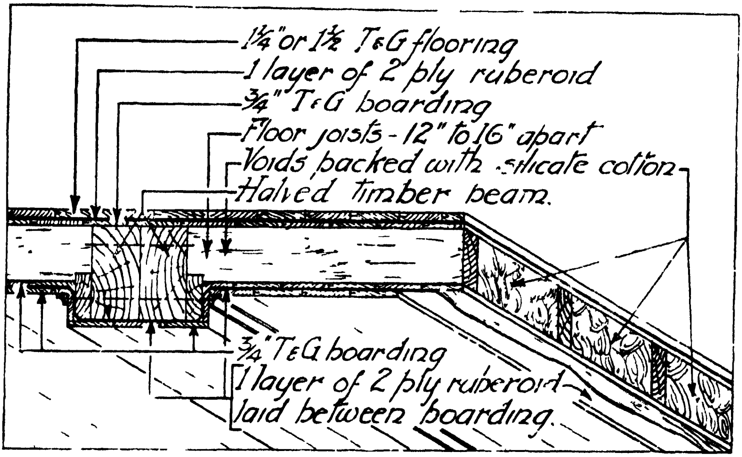
1¼" or 1½ T&G flooring
1 layer of 2 ply ruberoid
¾" T&G boarding
Floor joists - 12" to 16" apart
Voids packed with silicate cotton
Halved timber beam.
¾" T&G boarding
1 layer of 2 ply ruberoid laid between boarding.

FIG 89

Floors. With the ordinary timber floor the simplest method of insulation is to pack the material to be used between the floor joists, boarding these up on the under side as shown in Fig. 89. The filling will then, as a rule, be of considerably greater thickness than is necessary for insulation purposes, but it will probably be simpler and cheaper to fill the spaces with the insulating material rather than to subdivide them with a layer of intermediate boarding. It is not advisable to leave them only partially filled with insulation, as apart from other things, unless silicate cotton is used, the space makes an excellent harbour for vermin.

With concrete floors the cork insulation should be fixed on the under side only, as shown in Fig. 90, never on the floor itself

Columns and Beams. Any internal iron or steel columns and steel girders that may be used in the construction of a cold store should be insulated in a similar manner, and with the materials that are being used for the insulation of the walls. One method of fixing an insulation of cork board round a steel stanchion is shown in Fig. 91. It can also be surrounded with concrete to which the cork is fixed.

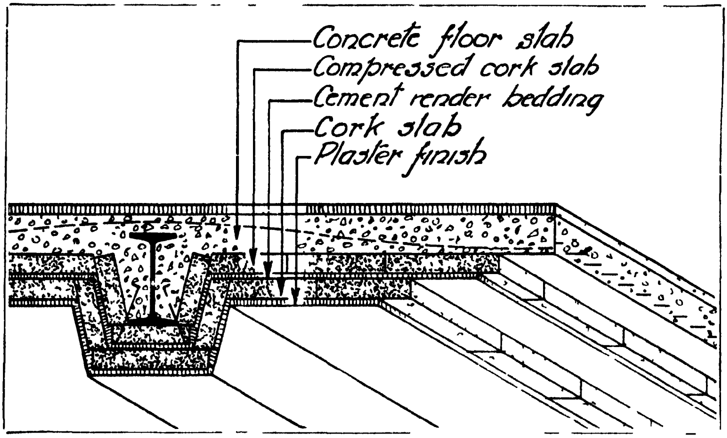

FIG. 90

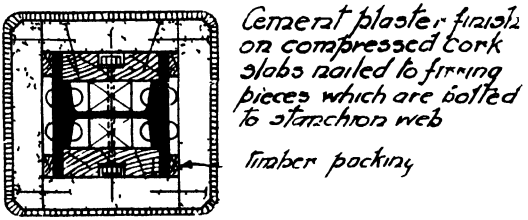
Cement plaster finish on compressed cork slabs nailed to firring pieces which are bolted to stanchion web
Timber packing

FIG. 91

Pipes and Tanks. Pipes conveying cold brine or the suction pipes of a refrigerating machine should be insulated as shown in Fig. 92. Great care must be taken to keep the external surface air and waterproof, by frequent painting, for if once the frost gets in the insulation will blow off, and of course

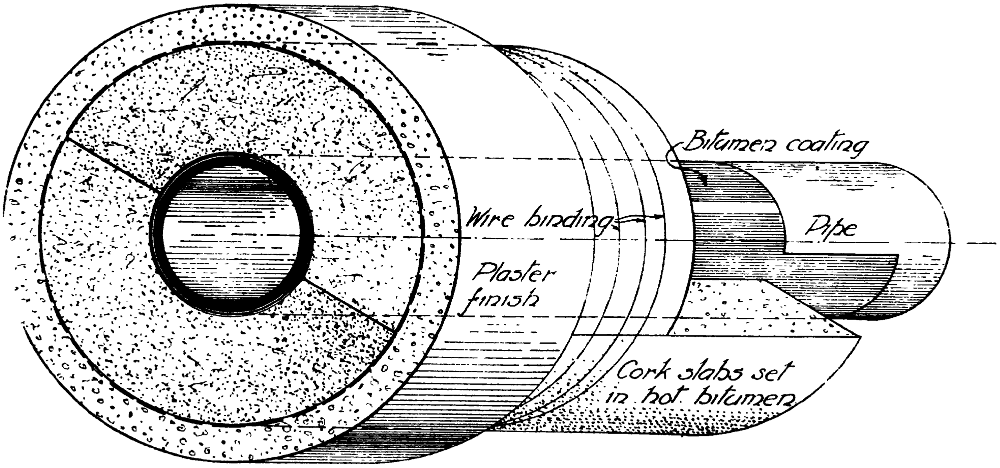
Bitumen coating
Pipe
Wire binding
Plaster finish
Cork slabs set in hot bitumen

FIG. 92

become useless. Aquaseal, which is referred to later, is particularly suitable for use as an external finish for cork sections on cold piping, as, when properly applied, it is entirely impervious.

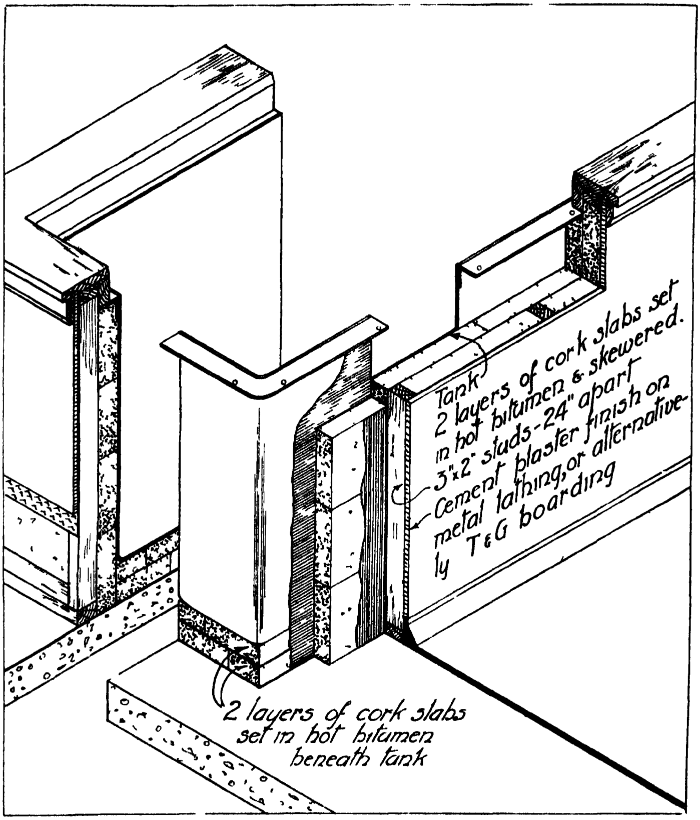
Tank
2 layers of cork slabs set in hot bitumen & skewered.
3"x2" studs-24" apart
Cement plaster finish on metal lathing, or alternatively T&G boarding
2 layers of cork slabs set in hot bitumen beneath tank

FIG 93

Fig. 93 illustrates the method of insulating an ice tank with cork slabs.

Interior Finish. There is considerable difference of opinion as to the most suitable finish for the interior wall surfaces for cold storage rooms.

Some small rooms have a glazed brick or tile finish which gives a very attractive appearance, but there is apt to be more condensation from incoming warm air when the doors are open than with timber construction, and this rather detracts from the effect, whilst the cost is prohibitive in all but quite small rooms.

Insulation of cork slabs is usually finished in a hard setting cement brought up to a fine surface and sometimes enamelled. This makes a good impervious surface that can be washed down without damage to the insulation, and probably its only drawback is that it is easily damaged by the handling of heavy goods and boxes, etc. This is particularly the case in corridors and entrances, where much trucking is done, and it is very necessary either to provide suitable dunnage rails or battens as in Fig. 94, or galvanized iron plates.

The cement is applied to the cork slab insulated walls in the following manner. They are first rendered in ordinary portland cement stucco from ½ in. to ¾ in. thick in preferably two coats, though sometimes these are combined in one coat. the proportion of the mix being 1 of portland cement to 2½ or 3 of clean, sharp sand. The final coat consists of 2½ parts of washed silica or silver sand to 1 of white portland cement. In three coat work, the first coat should be ¼ in. thick and heavily scratched. The second coat should be applied within twenty-four hours, the previous coat being damp but not wet. This second coat should be ⅜ in. thick, floated with a wooden trowel and lightly scratched. The third coat should not be applied until the under coats have thoroughly hardened, that is for not less than seven days. It should be from ⅛ in. to $\frac{3}{16}$ in. thick, and the under coat should be made damp. It should be finished with a bright, clean, steel trowel, but must not be excessively trowelled, or the colour will suffer. In best work galvanized expanded metal lathing is first secured to the cork slabs (or studs) by galvanized staples, the three coat work following as previously described.

With loose fillings the interior surface is always of T. & G. boarding. Some users prefer to leave this boarding without any protective covering. Being absorbent, it will not show up condensation, and it is argued that any surface moisture absorbed on occasions will dry out again. An absorbent surface is, however, objectionable in that it will take up any odours. It provides a good ground for the development of moulds, and if it is infected it is almost impossible to prevent moulds spreading to goods, such as meat, which may be placed in the rooms. It is also much more liable to rot.

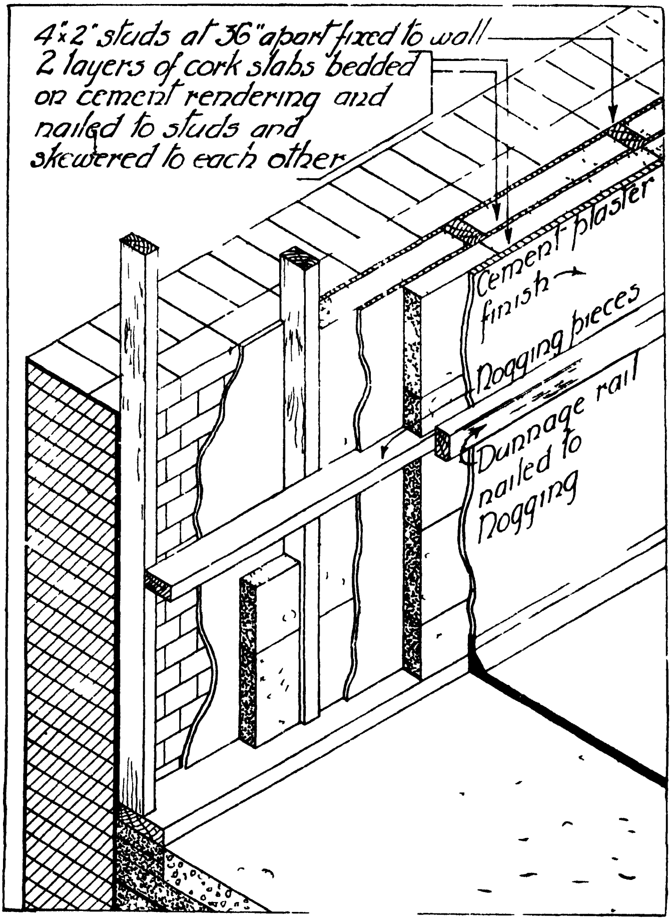
4"x2" studs at 36" apart fixed to wall
2 layers of cork slabs bedded on cement rendering and nailed to studs and skewered to each other
Cement plaster finish
Nogging pieces
Dunnage rail nailed to nogging

Fig. 94

Another method of finishing the surfaces of cold storage rooms is by using an emulsified asphalte preparation, such as Aquaseal.* This is not liable to crack in the way that cement does. It is particularly suitable for some special installations, and for particularly low temperatures, but as it is soft and easily pierced it should only be used in cases where it can be completely protected by dunnage battens.

It is necessary that the temperature should not fall below 45° F. during the application and setting of these asphaltic emulsions, and in spaces such as insulated rooms, which are usually airless when under construction, the process of drying is sometimes a lengthy one. The natural colour is, of course, black, and ordinary paints cannot be used, but either aluminium paint or a special tar-resisting paint can be used to give a light finish. Aquaseal will take distemper quite well, and this is often quite good enough, especially in large rooms.

Special insulating varnish is very largely used for finishing woodwork. It forms a hard surface, which renders it airtight, so that it will not absorb smell or moisture, and it looks clean, so that in these respects it is very satisfactory.

White paint with an enamel finish makes a very good finish, especially for small stores. The paint fills up the pores of the wood and provides a moisture and odour proof surface which is very largely permanent.

Lime washing as a covering is cheap and easily applied. It is neither damp nor moisture proof, but has the advantage of being a disinfectant. It has, however, to be renewed frequently, which is a tiresome and costly operation.

Tests. Numerous tests have been made to determine the rate of the flow of heat through insulating materials used for cold storage purposes, and with the earlier and generally somewhat crude methods the results varied to a considerable extent.

There are now available the results of tests carried out by the National Physical Laboratory for the Engineering Committee of the Food Investigation Board, and by the United

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* Messrs. Berry, Wiggins & Co., Ltd., London.

States Bureau of Standards. These are summarized in the following Tables.

It will be seen that there is a substantial agreement between the two figures, and they also confirm the tests carried out by Doctor Nusseult and other authorities.

In using these figures it must be remembered that all insulating materials are in themselves of a more or less variable nature, that the exact figures may be influenced by the density of the packing, details of construction, and quality of workmanship. In any calculations to determine the refrigerating power required, a margin of at least 15 and preferably of about 20 per cent should be added to cover these possible variations.

Since these tests were made several new insulating substances have been experimented with by the Food Investigation Board, but so far they are not in commercial use.

Nicold Insulating Board.* This has been developed as a substitute for baked cork board for low temperature thermal insulation. It is manufactured in England and, according to tests made by the National Physical Laboratory, possesses a thermal conductivity of 0·28 B.T.U. per sq. ft./°F./hr./1 in. thickness. Its density is 6¾ lb. per cubic foot, and it has a modulus of rupture in lb. per square inch of 24·1. In its manufactured form it does not easily absorb water, and it will not harbour vermin.

Expanded Rubber. This is ordinary rubber expanded into a highly cellular form by being vulcanized under a very high pressure. The conductivity is lower than that of cork and only 1½ times that of still air.

Unifil. This material, which can be produced at a low price, is much used in Australia and New Zealand. It is manufactured from the non-metallic mica ore Vermiculite by subjecting it to a high temperature, which produces air cells between the laminations. It is moisture and vermin proof, can be used loose, in sheets, or monolithically as the aggregate in concrete. It is said to have a thermal conductivity of 0·286, or in a 10 — 1 concrete mix 0·68.

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* Newalls Insulation Company, Broxbourne, England.

Celotex.* Celotex is produced from cane fibre and is marketed in the form of waterproof boards, $\frac{1}{4}$ in. and $\frac{7}{16}$ in. in thickness, 4 ft. wide and in various lengths. It has been tested by the National Physical Laboratory, and was found to have a resistance to heat transmission equal to pure cork board.

Alfol.† Alfol consists of very thin and lightly crumpled sheets of aluminium. Tests made at the National Physical Laboratory have shown that it has a heat transmission of 0·29 B.T.U. per hour per square foot and one inch thickness, and on account of its very light weight per cubic foot it is particularly suitable for the insulation of refrigerated vehicles. It is referred to further on page 477.

Rock Cork.‡ This is a low temperature insulating material made from mineral wool and moulded into sheet form. A marked characteristic of rock cork is its great resistance to moisture and its non-absorption of odour. In common with similar products of a mineral nature, it is immune to termites, vermin and mould. Its conductivity is 0·33 B.T.U. per sq. ft./ °F./hr./1 in. thickness, at mean temperatures below 100° F., and is available in sizes 18 in. × 36 in., $1\frac{1}{2}$ in. to 4 in. thick, and 18 in. × 18 in., 1 in. thick. The weight of rock cork sheets is 15 lb. per cubic foot. It is also made in granular form.

Stillite.§ This is a mineral wool manufactured from selected slag of special chemical composition. This, and the manufacturing process, produces a wool of superfine fibres, the diameters of which are said to range from 0·0001 cm. to 0·0015 cm. and average 0·0005 cm The wool so produced is of a pliable and resilient nature, and does not possess the same tendency to settle or pack, as is the case with ordinary slag wool.

In the process of manufacture, each fibre may be treated individually with a water repellent, and the final product is odourless. The weight does not exceed 10 lb. per cubic foot when packed in a container and subjected to the pressure of a 15 lb. weight. At this density, the thermal conductivity is as follows—

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* Messrs. The Celotex Co., of Great Britain, Ltd., 324 Australia House, London, W.C. 2.

† Alfol Insulation, Ltd., Windsor House, Victoria Street, London, S.W.1.

‡ Johns–Manville Company, Ltd., London.

§ Stillite Products, Ltd., Stillington, Durham, England.

Mean Temperature	*Thermal Conductivity in B.T.U./sq. ft./hour/° F./inch*
0° F.	0·22
32° F.	0·24
50 F.	0·25

In practice the packing density used by some consulting engineers is 12 lb. per cubic foot.

Stillite is also manufactured in slabs of standard size and thickness, which will take cement render or bitumen finish.

TABLE*

THERMAL CONDUCTIVITIES OF VARIOUS MATERIALS

All the figures given below, with the exception of the first two, are the results of measurements made at the Bureau of Standards, Washington, D C., on the representative samples of materials They represent actual internal conductivities, surface effects having been eliminated. The mean temperature of the determination was about 25° C, and the temperature differences used varied from 10 to 25° C

March 6, 1918

Material	Description	Conductivity.		Density	
		K	*k.*	*D.*	*d.*
Vacuum	Silvered vacuum jacket residual air pressure about 0·001 mm. H.G . .	000002	0·1		–
Air .	Ideal air space—if radiation or convection could be prevented . .	000060	4 2	0012	0 08
Calorox	Fluffy finely divided mineral matter	000076	5 3	·061	4·0
Kapox	Imported vegetable fibre—loosely packed .	000082	5 7	014	0 88
Pure wool	——	000084	5·9	11	6 9
Pure wool .	——	000084	5 9	·10	6·3
Hair felt .	——	000085	5·9	·27	17·0
Pure wool . .	——	000090	6 3	·08	5 0
Keystone hair .	Hair felt confined with building paper flexible .	·000093	6 5	·30	19 0

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* Reproduced from *Ice and Refrigeration* April 1918

TABLE—THERMAL CONDUCTIVITIES OF VARIOUS MATERIALS (*contd.*)

Material.	Description.	March 6, 1918.			
		Conductivity.		Density.	
		K.	*k.*	*D.*	*d.*
Mineral wool	Medium packed	·000095	6·6	·20	12·5
Corkboard	No artificial binder—low density	·000096	6·7	·11	6·9
Mineral wool	Felted in blocks	·000099	6·9	·29	18·0
Cotton wool	Loosely packed	·000100	7·0	—	—
Pure wool	———	·000101	7·0	·04	2·5
Insulite	Pressed wood pulp—rigid	·000102	7·1	·19	11·9
Linofelt	Vegetable fibre confined with paper—flexible and soft	·000103	7·2	·18	11·3
Ground cork	———	·000102	7·1	·15	9·4
Corkboard	No artificial binder—high density	·000106	7·4	·18	11·3
Celite	Infusorial earth powder	·000106	7·4	·17	10·6
Granulated cork	About $\frac{3}{16}$ in. thick	·000107	7·5	·13	8·1
Cabot's quilt	Eel grass enclosed in burlap	·000110	7·7	·25	16·0
Flaxanum	Felted vegetable fibres—firm and flexible	·000113	7·9	·18	11·3
Fibrofelt	Felted vegetable fibres—firm and flexible	·000113	7·9	·18	11·3
Rock cork	Mineral wool and binder—rigid	·000119	8·3	·33	21·0
Balsa wood	Very light and soft—cross grain	·00012	8·4	·12	7·5
Wool felt	Flexible paper stock	·000125	8·7	·33	21·0
Lith board	Mineral wool vegetable fibres and binder—rigid	·000131	9·1	·20	12·5
Planer shavings	Various	·00014	10·0	·14	8·8
Pulp board	Stiff pasteboard	·00015	11·0	—	—
Air cell ½ in.	Corrugated asbestos paper enclosing air spaces	·00015	11·0	·14	8·8
Air cell 1 in.	Corrugated asbestos paper enclosing air spaces	·00017	12·0	·14	8·8
Asbestos paper	Asbestos and organic binder	·00017	12·0	·50	31·0
Infusorial earth	Natural blocks	·00020	14·0	·69	43·0
Fire felt sheet	Soft, flexible asbestos sheet	·00021	14·0	·42	26·0
Fire felt roll	Asbestos sheet coated with cement—rigid	·00022	15·0	·68	43·0
Cypress	Across grain	·00023	16·0	·46	29·0
Fuller's earth	Argillaceous powder	·00024	17·0	·53	33·0
Tar roofing	———	·00024	17·0	·88	55·0
White pine	Across grain	·00027	19·0	·50	32·0
Asbestos mill board	Pressed asbestos—not very flexible	·00029	20·0	·97	61·0
Mahogany	Across grain	·00031	22·0	·55	34·0
Insulex	Asbestos and plaster blocks, porous	·00031	22·0	·47	29·0
Virginia pine	Across grain	·00033	23·0	·55	34·0
Oak	Across grain	·00035	24·0	·61	38·0
Hard maple	Across grain	·00038	27·0	·71	44·0
Hard maple	Across grain	·00038	27·0	·71	44·0
Paraffin	"Parowax" melting point 52° C.	·00055	38·0	·89	56·0
Gypsum plaster	———	·00078	54·0	—	—
Asbestos wood	Asbestos and cement—very hard and rigid	·00093	65·0	1·97	123·0

K = Thermal conductivity in calories per sec. per sq. cm. per degree C. per cm. thickness.
k = Thermal conductivity in B.T.U. per day per sq. ft. per degree F. per inch thickness.
D = Density in grams per cu. cm.
d = Density in lb. per cu. ft.
$69{,}700K = k$.
$62·5D = d$.

TABLE

THERMAL CONDUCTIVITY

Tests Made by the Food Investigation Board, 1921*

Material.	Gramme-calories per sq. cm. per sec., for 1 c.m. thickness and for 1° C. diff. in Temperature.	B.T.Us. per sq. ft. per hr. for 1 in. thickness and for 1° F. diff. in Temperature	Temperature Range.	Mean Temperature of the Insulating Material.
Charcoal. (Three dependent series of experiments with altered conditions and samples from two sources.)	0·000120	0·348	11° C. to 46° C. 11° F. to 115° F.	17° C. 120° F.
	0·000120	0·348	15° C. to + 5° C. 7° F. to 41° F.	– 5° C. 22° F.
	0·000127	0·370	13° C. to 9° C. 8° F. to 48° F.	- 2° C. 28° F.
Diatomaceous earth.	0·000193	0·560	- 11° C. to 9° C. 9° F. to 49° F.	– 1° C. 30° F.
Packed 30 lb. per cu. ft. (approx.).	0·000215	0·624	14° C. to 32° C. 58° F. to 89° F.	23° C. 74° F.
	0·000224	0·644	30° C. to 115° C. 86° F. to 239° F.	72° C. 162° F.
	0·000228	0·662	23° C. to 64° C. 74° F. to 146° F.	
Diatomaceous brick.	0·000223	0·647	15° C. to + 27° C. 4° F. to 80° F.	+ 6° C. 42° F.
Do. (crushed to powder)	0·000300	0·870	- 9° C. to 15° C. 16° F. to 59° F.	3° C. 37° F.
Cellular brick (made up of cardboard).	0·000225	0·653	8° C. to 4° C. 17° F. to 39° F.	2° C. 28° F.
	0·000236	0·686	13° C. to 21° C. 55° F. to 70° F.	17° C. 63° F.
	0·000282	0·820	38° C. to 82° C. 100° F. to 180° F.	60° C. 140° F.
Wood (pitch pine of good quality).	0·000357	1·036	20° C. to 32° C. 67° F. to 91° F.	26° C. 79° F.
Facing cement (magnesium oxychloride composition).	0·00038	1·010	– 8° C. to 2° C. 16° F to 36° F.	– 3° C. 26° F.
"Lyxhayr" (fibre from eucalyptus tree).	0·000107	0·311	12° C. to + 12° C. 10° F. to 54° F.	0° C. 32° F.
Bitumen composition (used for flooring and constructional work).	0·0020	5·9	20° C. to 33° C. 66° F. to 92° F.	26° C. 79° F.
Concrete block (used for constructional work)	0·0028	8·2	16° C. to 46° C. 60° F. to 115° F.	31° C. 88° F.

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* Special Report, No. 5, H.M. Stationery Office, London. 3s. net.

TABLE

Thermal Conductivity

Material.	Gramme-calories per sq. cm. per sec., for 1 c.m. thickness and for 1° C. diff. in Temperature.	B.T.Us. per sq. ft. per hr. for 1 in. thickness and for 1° F. diff. in Temperature.	Temperature Range.	Mean Temperature of the Insulating Material.
Slab cork (baked) Sample No. 1. .	0·000117	0·339	22° C. to 96° C. 70° F. to 204° F.	58° C. 136° F.
	0·000113	0·329	13° C. to 25° C. 55° F. to 77° F.	20° C. 68° F.
	0·000114	0·331	14·5° C. to - 1·7° C. 6° F. to 29° F.	- 8° C. 17·6° F.
Sample No. 2. .	0·000105	0·306	- 8° C. to + 10° C. 16° F. to 50° F.	+ 1° C. 33° F.
	0·000107	0·311	19° C. to 37° C. 66° F. to 98° F.	28° C. 82° F.
Sample No. 3. From a warship after ten years' service.	0·000102	0·295	27° C. to 58° C. 80° F. to 128° F.	40° C. 104° F.
Granulated cork (fine). Sample No. 1.	0·000103	0·298	- 9° C. to + 9° C. 15° F. to 49° F.	0° C. 32° F.
Granulated cork (coarse): Sample No. 1 (packed* 5·3 lb. per cu. ft.).	0·000112	0·326	9° C. to 15° C. 16° F. to 58° F.	3° C. 37° F.
(Packed* 5·4 lb. per cu. ft.)	0·000110	0·319	11° C. to + 1° C. 10° F. to 34° F.	- 5° C. 22° F.
Sample No. 2 (packed 7·3 lb. per cu. ft.).	0·000118	0·345	- 15° C. to 8° C. 4° F. to 46° F.	- 3·5° C. 25° F.
Cork plaster. .	0·000135	0·390	7·5° C. to 6° C. 18° F. to 42° F.	- 1° C. 30° F.
Slag-wool: packed 13 lb per cu. ft. approx.).	0·000104	0·302	16° C. to 18° C. 4° F. to 64° F.	1° C. 33° F.
Packed 21 lb. per cu. ft. (approx.).	0·000100	0·290	- 15° C. to 1° C. 6° F. to 33° F.	- 7° C. 19° F.
Sample taken from a warship after fourteen years' service.	0·000121	0·353	6° C. to + 6° C. 21° F. to 42° F.	0° C. 32° F.
Sample greatly deteriorated by vibration.	0·000145	0·422	11° C. to 8° C. 10° F. to 48° F.	- 2° C. 29° F.
Sample felted to mats with organic binder.	0·000105	0·305	8° C. to 6° C. 18° F. to 42° F.	- 1° C. 30° F.
	0·000112	0·327	21° C. to 33° C. 70° F. to 92° F.	27° C. 81° F.

Two separate experiments with conditions varied considerably.

CHAPTER IX

BRINE

THE object of using brine in connection with refrigerating plant is to obtain a liquid capable of being cooled to the temperatures required for any particular purpose without freezing. Thus in can ice-making tanks it is usual to have the brine at about 14° to 16° F.

Comparison of Sodium and Calcium Chlorides. A solution of calcium chloride is generally used. A solution of common salt or sodium chloride answers almost equally as well as a non-freezing liquid with the temperatures ordinarily employed, but it has certain serious disadvantages. Generally speaking, chloride of calcium and chloride of sodium are similar in character. The former is the more energetic moisture-absorber for whereas salt will only absorb sufficient moisture to make it damp, chloride of calcium will absorb nearly its own weight of water and become liquid. It has accordingly been used to a great extent as a moisture-absorber in connection with processes requiring a dry atmosphere.

One great objection to sodium brine is that it rusts the steel with which it is in contact, causing corrosion of the ice-making or other brine tanks, ice-moulds, and pipe systems. This corrosive effect which is practically absent when calcium chloride is used can, however, be largely neutralized by adding 1 lb. of caustic soda for each 100 lb. of sodium chloride used.

A property of all solutions is that the proportion of salt required to make a saturated solution decreases with a fall in temperature. Thus, if a saturated solution is made at ordinary temperatures and is then cooled, it will remain saturated, but a proportion of the salt will separate out until the eutectic point, which is the temperature at which the liquid as a whole passes into the solid state is reached.

With calcium chloride the eutectic point is – 58° F. for 4·25 lb. in one gallon of water, or a 30 per cent solution with a specific gravity of 1·289.

With sodium chloride the eutectic point is − 6·16° F. for 2·89 lb. in one gallon of water, or a 22·2 per cent solution with a specific gravity of 1·170.

At 60° F. a saturated solution of sodium chloride contains 2·64 lb. per gallon of solution and has a specific gravity of 1·204. If used in a refrigerating plant a considerable amount of salt would separate out of this brine when cooled, causing a deposit in the tanks and choking the pipe connections. With calcium chloride the saturated state is so far outside the normal range of temperatures and density of solution that a deposit from this cause is practically impossible.

The density of the solutions given in the tables is taken at 60° F., so that brine should be warmed up or cooled down to this temperature before a proper test of its density can be made.

A practical rule for making up a sodium chloride brine is to use 3 lb. of salt for each gallon of water.

It is most important that there should be no freezing of the solution. If it occurs the evaporation pipe surfaces are at once partially insulated, and this automatically causes a lower temperature of evaporation, which in its turn increases the freezing on the surfaces. The bad effects increase progressively until the work done by the refrigerating machine is reduced to zero. The brine supply freezing the water in an ice skating-rink was once stopped in this way. The calcium chloride froze solid on the cooling coils, which were of the Baudelot type ; the ice surface refused to form, and the public left in disgust. When the fault was discovered, it was found to be due to a new engine-driver, who had closed his regulating valves too much, and was carrying a very low back pressure, and so temperature, in the coils.

When the ammonia evaporator is of the double-pipe or shell type where the brine passes through piping surrounded by the ammonia, it is most important that the brine should be drained out before pumping these out or exhausting the ammonia. Otherwise the very low temperatures which are reached are liable to cause freezing of the brine with the risk of bursting the pipes.

The density of the brine solution is ascertained by means of a hydrometer. In England, Twaddle's hydrometer is generally used, and in the United States the Beaumé hydrometer is frequently employed.

For ice making and ordinary cold storage purposes, calcium chloride brine is generally made with a density of 1·2, and for specially low temperatures of 1·25.

Calcium chloride is a by-product of the chemical works. It is obtained in large quantities in the manufacture of salt, CO_2, and ammonia, and it is usually sold in a solid form in drums, though it is also prepared in granulated form and put up in drums or barrels. This latter form is considerably more convenient in use, especially when small quantities only are required, or when additions of calcium have to be made to the brine system to maintain it at its correct density.

Commercial calcium chloride as sold contains about 25 per cent of water, and this has to be allowed for in calculating the mixtures.

Calcium chloride brine attacks cement, reducing it to the consistency of soft putty. Great care therefore should be taken to see that the chemical or the brine does not come in contact with cement, and for this reason rock asphalt should be used for all floors or surfaces liable to brine splash.

Making the Brine Solution. Sodium chloride brine can be made in any simple way. Avoid putting the salt into the

PROPERTIES OF SODIUM CHLORIDE BRINE *

Specific Gravity at 60° F.	Percentage of Anhydrous Sodium Chloride	Degrees, Twaddel	Freezing Point.
1·025	3·6	5	28·5° F
1·050	7·0	10	24·75
1·075	10·25	15	20
1·100	13·5	20	13·75
1·125	16·75	25	7·5
1·15	19·9	30	0·5
1·17	22·2	39	6·0

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* Taken from the diagram on p 32 of Special Report No 4, Department of Scientific and Industrial Research Food Investigation Board

PROPERTIES OF CALCIUM CHLORIDE BRINE

Specific Gravity.	Degrees, Twaddel.	Percentage of Anhydrous Calcium.	Weight of Commercial Calcium required for 1 gall. of Brine.	Freezing Point.
1·025	5	3	·42 lb.	29·4° F.
1·050	10	6	·86	26·5
1·075	15	9	1·31	23·0
1·100	20	12	1·78	18·6
1·125	25	14·5	2·20	13·5
1·150	30	17	2·65	7·5
1·175	35	19·5	3·10	0·0
1·200	40	22	3·65	9·0
1·225	45	24·5	4·05	20·0
1·250	50	27	4·57	32·6
1·275	55	29·5	5·08	50·0
1·283	56·6	30	5·2	54·4

SPECIFIC HEAT OF CALCIUM CHLORIDE BRINE*

Temperature.	Density,† 1·19. Twaddel † 38	Density,† 1·20. Twaddel,† 40.	Density,† 1·21. Twaddel,† 42.
- 25° C.	0·697	0·685	0·674
20	0·702	0·690	0·679
15	0·707	0·695	0·684
10	0·712	0·700	0·689
5	0·717	0·705	0·694
0	0·722	0·710	0·699
5	0·727	0·715	0·704
10	0·732	0·720	0·709
15	0·737	0·725	0·714
20	0·742	0·730	0·719

* Taken from the Report of the Refrigeration Research Committee. Institute of Mechanical Engineers, 1914; p. 14.

† The density is measured at 60° F. (15·5° C.) (Nat. Phy. Lab. Report, 1909).

ice tanks and trying to mix it there. It will be exceedingly difficult, and the salt will cake on the bottom of the tank and on the lower expansion pipes. The brine should always be mixed in a separate vessel, and then put into the tanks. An ordinary way of doing this is to make a false bottom to a common barrel or box, perforate this with small auger holes, and fix it some three or four inches above the real bottom. Put the salt or chloride into the barrel and fill it nearly to the top. Connect up the bottom portion to a hose, turn on the water, and let it rise up through the salt. A pipe should be connected to the side and near the top of the barrel as an outlet for the brine, and the water supply to the bottom should be regulated to prevent any overflow from the open top of the barrel.

The brine should be strained as it flows away from the barrel in order to rid it of any impurities or dissolved salt. It is best to mix brine rather stronger than is wanted, and dilute it down to the proper strength by the subsequent addition of water.

In preparing brine from calcium chloride, the method usually adopted is to mix the calcium and water in a tank in such proportions as will give a higher density than that actually required. The mixture should be stirred round until solution is complete. It is best to avoid putting the calcium in the ice tank, though this is not so bad as in the case of salt. Mixing will be facilitated if the water is warmed up by a steam coil.

Regenerating Brine. As the brine, particularly in cold storage plants using air circulation, is constantly absorbing moisture from the air, it is necessary in order to keep it at its proper strength to either regenerate it by adding more salt or calcium, or to concentrate it by evaporating off the absorbed and surplus moisture.

The air cooler or other tanks have generally only a small range of capacity, so that as a rule it is necessary to run away the surplus solution to regain the normal working level, and add sufficient calcium to the remainder to increase its density to the correct degree

Quite apart from the labour and mess involved whenever fresh calcium is added, concentration is the better method when steam or heat is available. This is not only on account of the saving in the cost of calcium, but also because the brine usually contains some insoluble matter which, with constant additions, tends to accumulate in the tanks and pipes, restricting the circulation.

A simple apparatus for concentrating brine and bringing its strength up to whatever density is required, consists of a steam-jacketed pan, very similar to those used for jam-boiling or lard-melting. The brine, as it requires to be concentrated, is run into the pan from the battery tank. Live steam is admitted into the jacket and the brine in the copper boils, the excess water being driven off as steam, or in place of the jacketed pan a tank—preferably of cast iron—can be used with a simple steam-heating pipe coil. An ample tank capacity should be provided, as the brine froths considerably in boiling, also the apparatus should preferably be in the open air, as any odours absorbed by the brine from the goods in store are driven off in the process of boiling. After the brine has been concentrated sufficiently and has cooled down, it is drained off to the brine pump and re-absorbed into the system.

In very large plants, where a considerable amount of moisture is absorbed by the brine as the air passes over the battery, the brine has to be frequently concentrated. In this case the method shown in Fig. 95 is used. In the diagram, *A* is a steam-jacketed copper pan similar to that just described ; *B* is a tank which contains the hot brine just concentrated, and *D* is a warm brine tank. When the apparatus is at work, a charge of cold brine is put into *A* and concentrated to the proper density ; it is then discharged hot into *B*. Cold brine requiring to be concentrated flows from the battery tank through the pipe *C* and through the coils in *B* into the tank *D*. In passing through the coils it is warmed by the hot brine in the tank, and when it enters *D* is already hot. The concentrated brine is correspondingly cooled. The coil in the tank *B* thus becomes a heat interchanger and saves fuel by warming up the cold brine. This interchanger may be of the open-air type, and if this is adopted, the hot brine is further cooled by the action of the atmosphere.

The cooler is usually just below the level of the battery tank, and the brine is gravitated through the coil in *B* into the tank *D*, the supply being regulated by the valve shown. In this case it has, of course, to be returned to the tank by a pump. When the concentrator is not in continuous use the tank *D* may be omitted. In practice the copper *A* is fitted with a bonnet to catch and carry off the steam.

It has been proposed as a method of concentrating brine that the weak solution run off from the cooler tanks should be used as the cooling medium, either for a part of or for the whole condenser, and that it should be circulated both over the condenser and an ordinary water re-cooling apparatus

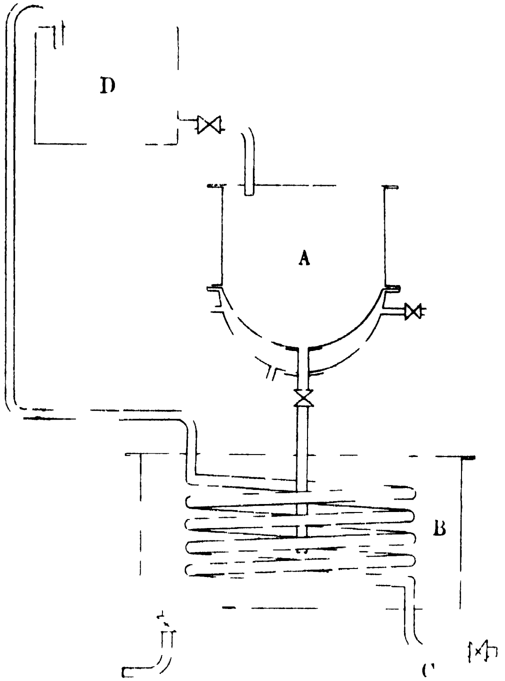

Fig 95

Partial evaporation would be effected in the latter, and the brine would thus be concentrated by using the heat of condensation of the refrigerant without the use of steam or any separate or external source of heat.

When refrigerating plants are electrically-driven, an ordinary boiling copper, set in brickwork and fired with coke, can be employed, or a self-contained boiling copper like those used by caterers at fairs or shows can be used. These are quite satisfactory for small plants.

CHAPTER X

ICE MAKING

ONE of the very important uses to which mechanical refrigeration has been put is the freezing of water to produce ice.

Refrigerating Capacity Required for Making Ice. It has been shown in Chapter VI that about 220 B.T.U. must be extracted to make 1 lb. of ice from water at 60° F. The temperature of the water is as a general rule an index of the general conditions, and in hotter climates the losses through the insulation, etc., will be greater. On medium and the larger size ice-making plants, the refrigerating power may be taken as—

Initial Temperature of Water to be Frozen.	*B.T.U. Required per lb. of Ice.*
60° F.	220
70° F.	233
80° F.	246
90° F.	260

Water for Ice Making. Practically any water that is fit to drink will make ice that is fit to use. In the majority of plants the water to be frozen is drawn from a public supply, and its purity is beyond question ; but where the water is drawn from wells or other private sources of supply, care should be exercised to see that it is perfectly healthy.

At one time large quantities of ice from the Norwegian lakes were imported into England. Although there was no question of the quality or purity of this natural ice—in fact, it often commanded a higher price than the manufactured ice from fishmongers, etc., who wanted large and attractive blocks for display purposes—the trade has practically ceased.

The falling-off in the quantity of ice imported is due to the increase in the number and capacity of the ice manufacturing plants in England, to the improvements in the quality and clearness of manufactured ice, to the rapidly growing practice of employing small refrigerating machines, and, in special cases, dry-ice for purposes for which ordinary ice was previously used.

Until about 1912 practically all the ice-making plants in the United States and numbers in other parts of the world distilled the water to be used for ice-making. There was the advantage that the ice produced had a high degree of transparency, and there was a very considerable commercial value attached to the expression "ice made from pure distilled water" as signifying freedom from pathogenic bacteria.

In point of fact, the attention given to the filtering arrangements and plants generally was not, as a rule, sufficient to ensure that condition, and from the point of view of purity the ice was often little if any better than that made from the public supplies.

Quality of Ice. If a can or mould is filled with distilled and de-aerated water and frozen solid, the block of ice will be practically clear and transparent throughout with only a very thin film in the centre. If, on the other hand, water from any ordinary supply is used the ice will be opaque, and as it resembles a coarse, white marble, and is frequently in blocks of similar size, it is sometimes referred to as tombstone ice.

The opacity is due to the air and to the mineral salts in solution in the water, which are precipitated out as it freezes.

The air forms as a multitude of minute globules, which are imprisoned in the block and cause it to appear white and opaque throughout. The salts and any matter in suspension largely remain in the diminishing central core of water and, being finally frozen in, form an opaque and yellow core in the centre of the block.

The opacity due to air can be eliminated by effectively agitating the water during the period of freezing, so that the air bubbles are washed off the surface of the ice as fast as they form. The agitation also prevents the imprisonment of any solid matter, so that it is concentrated in a central core, leaving the block otherwise clear and transparent.

The mineral salts in solution are generally carbonates and sulphates of lime and magnesia; the extent and density of the core they form depends upon the quantity in solution, i.e. upon the hardness of the water, and it follows that better ice can be made from very soft waters. Where a supply is very hard it may be desirable to soften it before it is frozen, but as the large cores, which are otherwise formed from hard waters, can be greatly reduced by the system of withdrawing cores referred to later, the additional cost, complication, and cost of working a softening plant is seldom justified.

Opaque Ice. Opaque ice, such as is shown in Fig. 105,* is principally employed in the fishing and chemical industries, and as it is used and sold in a crushed form, its appearance is immaterial.

Generally speaking, it will melt more quickly, owing to the fact that the air it contains makes it porous, and by increasing the surface enables the heat to get at it more rapidly. On account of this it is often stated that it will do less refrigeration than a similar block of clear ice. This is not correct; the cooling effect from a given weight of ice will be the same whatever its appearance, but when used for an ice-cooled safe, the opaque ice, owing to its more rapid meeting, will effect its refrigeration in a shorter time. On a time basis, therefore, opaque ice will effect more refrigeration than a clear block, but as the user only wants his safe or box cooled, he prefers the block which lasts longer.

Ice for the Fish Trade. Recent experiments have shown that for preserving the catch on board a trawler, ice made from sea water is better than fresh-water ice. The fish appears to keep better and longer, and the edges of the ice being less sharp than fresh-water ice, do not tend to injure the fish.

Types of Ice-making Plant. There are three general methods of producing ice in current use, known as the can system, the cell system, and the plate system. Of these the first is now almost universal. The cell system had at one time a considerable vogue in England and in India. The plate system was largely used in the United States, and to a lesser extent in England and other countries, but with the exception of the "Pluperfect" system, which may be described as a modern development of the plate system, the two latter are rarely if ever installed in new plants, and are being replaced by can ice equipment in the older ones.

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* Lightfoot Refrigeration Co., Ltd., Bush House, London, W.C. 2.

The Can System. In making ice by this system, the water is frozen in terned or galvanized cans or moulds which are placed in a tank containing refrigerated brine. The brine surrounds the cans and is kept cold by contact with the surfaces of the evaporator, containing the refrigerating agent. The brine thus serves to transfer to the evaporating agent the heat which must be extracted from the water in order to freeze it.

The cans or moulds are of oblong shape, generally about three times as deep and twice as long as they are wide, and they are made in sizes to give a definite weight of ice of thickness and dimensions to suit the demand to be met.

Types of Can Ice-making Plant. Whilst there are considerable differences in the detail and construction employed by different makers, can ice-making tanks may be subdivided into two general types—

1. The type of tank developed and generally used in the United States, which has a wooden framework at the top, providing a separate space or compartment for each mould. The moulds, where they do not float, rest on bearers at the bottom of the tank. The ice moulds are handled singly, and the piping forming the evaporator is arranged as long coils placed between the rows of moulds.

2. The type developed in England and on the Continent in which each row of moulds is clipped together in a frame, so that a whole row is handled as a single unit, as shown in the illustration, Fig. 108, p. 273. In these tanks the evaporator pipe coils are closely nested together in a separate compartment of the tank placed sometimes at one side of the tank, sometimes in the centre, or, in Continental practice, almost invariably underneath the space occupied by the moulds.

With either type of tank the evaporator is frequently made of the shell type in preference to the pipe coil form, and occasionally the brine is cooled in coil or shell type evaporators that are entirely separate from and external to the ice tank proper.

The Distilled Water Ice Plant. While this is now almost entirely superseded by systems of agitation for the manufacture of clear ice, its use has been very extensive.

In the typical plant the exhaust steam from the driving engine was condensed, purified, and filtered to provide the supply of distilled water to fill the moulds.

The engine was usually of the single cylinder corliss type, working with steam at a pressure of about 100 lb. per sq. in., and exhausting against atmospheric pressure.

With an ammonia compressor the steam consumption of the engine was practically equal to the output of ice per day, and as steam had to be condensed for the full daily production, there was no point in incurring additional expenditure and complication to obtain a reduced consumption of steam in the engine.

The exhaust from the engine passed first through a separator to get rid of the bulk of the lubricating oil, and then through a tubular feed-water heater to the condenser.

An atmospheric relief valve was fitted in the exhaust pipe before it reached the condenser, in order to avoid the possibility of steam pressure on the exhaust side, and to give an alternative exhaust to atmosphere if required.

The condensate flowed to the re-boiling tank, which was a plain open tank fitted with a steam coil at the bottom. In this it was violently re-boiled to drive off any air and cause any grease or solid matter that had passed the separator, to rise to the surface The grease, etc., was then skimmed off through a suitable opening at the side of the tank. This opening generally communicated with a smaller tank or compartment, from which it could be drained away.

In some plants separate tanks were used for re-boiling and for skimming, but this was not usual.

The re-boiling tank was kept full by a float-controlled outlet valve. The float and valve themselves were contained in a separate small tank or vessel, communicating with the bottom of the re-boiling tank, so that the float was in still water. This avoided irregularity in working due to the boiling in the tank.

From this float-controlled outlet the water flowed through a cooler either of the Baudelot or double-pipe type, where it was cooled with the coldest water supply available.

The distilled water now cooled was passed through filters, generally two in series, and while both were generally filled with charcoal (animal or blood charcoal being the best filling), the first one was sometimes filled with quartz or sand.

From the filters the water passed to the storage tank, which was also made to serve as the fore-cooling tank and was usually insulated.

The tank was fitted with coils through which the return gas to the compressor from the evaporator coils in the ice tank passed, though in some cases the coils were fed by a separate circuit direct from the liquid receiver.

The storage tank had a tight-fitting cover, and a wood float slightly smaller than the inside of the tank was sometimes added to, as far as possible, keep the water from contact with the air.

On leaving the storage tank the water passed through a small sponge-filled filter to the ice-can fillers. The fillers were made with the outlet valve at the foot, as shown in Fig. 99, arranged so that it opened with the weight of the filler. They were also provided with a float, which closed the valve when the mould was filled to the required height, thus preventing the aeration that would have been caused if the water were poured in.

As distilled water is particularly corrosive, the whole of the parts had to be heavily galvanized to prevent both corrosion and contamination of the water.

The ammonia absorption machine was very suitable for distilled ice plants, as no oil is used, the generator forming in itself the condenser.

This type of plant was dependent entirely upon its boiler efficiency and, with its losses in the re-boiling, it was seldom possible to produce more than from five to six tons of ice per ton of coal.

To obtain a greater economy in working and still retain the advantages of the use of distilled water, some installations have been put down with more economical engines working condensing and either a separate multiple effect distilling plant to take care of the whole ice production, so that the re-boiling can be cut out, or a smaller one to make up the deficiency of steam from the engine.

In some cases, where the water supply is bad, multiple effect distilling plants have been installed to provide distilled water for ice making when the refrigerating machinery is driven from electric motors or suction gas or oil engines.

Air Agitation. Many methods of agitating the water in ice cans have been tried, and the use of air is now general. There are two methods in use known respectively as the low pressure and as the high pressure systems.

In the low pressure system a rotary blower is usually employed, which delivers the air at a pressure of 2 to 3 lb. per sq. in. into a series of pipes or headers arranged on the framing of the tank-top and placed below the covers. These have connections which couple up to a pipe—called a drop pipe—which is placed in the centre of each mould and extends down to within about 6 in. of the bottom. In some plants each mould is separately agitated. In this case the drop pipe is supported in a central position in the mould by a crossbar, which fits on the top of the mould and the drop pipe is connected to the air supply by a flexible hose and coupling.

With this arrangement two adjoining moulds are disconnected at a time, and the two hoses coupled together to prevent the escape of air at the free opening, which would otherwise reduce the quantity of air flowing through water in other moulds. Another construction is to make the drop pipes in pairs and seat them on automatic valves placed in a plug connection on the air main between two moulds, the valve being so arranged that when the drop pipes are in position its weight keeps the valve open, but when removed the valve is closed by a light spring.

The low pressure system with drop pipes has been practically exclusively developed and used in connection with tanks in which the moulds are placed singly.

In the high pressure system the air is introduced at the bottom of the mould. As the air-pipe connection to the bottom of the mould is in contact with the cold brine, the outside air, if used, has to be specially treated or a proportion of its vapour content will be condensed and frozen, blocking the air pipe or orifice to the mould, and causing the agitation to cease.

To overcome this difficulty the air is first compressed to a pressure of 12 to 15 lb. per sq. in., and then cooled to as low a temperature as possible before it is passed on to the air supply pipes serving the moulds.* In practice this appears quite sufficient, but as it is impracticable to cool the air absolutely to the brine temperature, a theoretical consideration of the problem would indicate that it would be advisable to compress the air to a gauge pressure of about 25 to 30 lb. per sq. in. Then, while in this state, to cool it to within six or seven degrees of the temperature of the brine, and pass it through a reducing valve so that the delivery to the moulds is at a pressure of about 12 to 15 lb. per sq. in.

An ordinary low pressure reciprocating compressor is generally used. It should be substantially constructed so that it will run continuously for long periods, and it should be of a type that minimizes the risk of lubricating oil being carried forward with the delivery air.

The air coolers may be either of the dry type, using direct expansion, or brine piping, in which case they should be in duplicate, so that one is always in use while the other is being thawed off ; or of the wet type, where the air is cooled by direct contact with brine from the ice tank.

The coolers also act as air receivers, and will keep up the air supply for a few minutes in the event of the air compressor stopping. For large plants a standby air compressor is desirable.

When the moulds are placed singly in the tank they are provided with a small pipe secured in one corner and extending to about the centre of the bottom plate. This pipe has a union at the top for coupling to the hose connections provided for each mould on the air service piping arranged on the tank top.

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* Recently experiments have been made without forecooling the air. The results were quite satisfactory but there would appear to be an element of risk, particularly on days when the atmosphere was humid.

When the moulds are arranged in frames, each mould is provided in the centre of the bottom plate with a special nipple with an air orifice about $\frac{1}{32}$ in. in dimeter. These nipples are connected to a header pipe or manifold extending under the whole length of the row, and carried up on one side to the top of the frame. At this point the pipe is fitted with a union, so that it can be connected through a flexible hose pipe to the air main which extends along one side of the tank. The air main is provided with a branch, stop valve, and hose connection for each row of moulds.

With this system it is necessary that the air connection should be made and air turned on before the moulds are lowered into the brine.

The advantages of the low pressure system are—

1. A lower first cost.
2. A lower consumption of power.
3. No necessity to specially cool and dry the air
4. No liability to freeze up the air pipes.

And its disadvantages are—

1. The air pipes have to be removed before the moulds are frozen solid, involving extra labour.
2. Inability to continue the operation whilst freezing up the centre portion or core.
3. A liability to freeze in the drop pipes if they are not removed in time, involving extra labour in thawing them out by introducing warm water into them.

The advantages of the high pressure system are

1. That the best possible quality of ice is obtained as the agitation is continued until the mould is frozen solid.
2. That the labour involved in removing the drop pipes is avoided.

And its disadvantages are

1. A greater first cost.
2. A greater consumption of power
3. The very small orifices are apt to become blocked with scale or dirt from the pipes.

4. The orifices will freeze up instantly if the air pressure drops.

The quantity of air to be provided per mould will vary with the hardness of the water, but should be about—

For 1 cwt. moulds	0·25 cu. ft. per minute.
2 ,, ,,	0·3 ,, ,, ,,
3 ,, ,,	0·35 ,, ,, ,,
4 ,, ,,	0·4 ,, ,, ,,

A complete ice tank, making clear ice and operating with air agitation, is shown in plan and section in Fig. 96.* All the auxiliaries are electrically-driven and are placed at the back end of the tank. The evaporating coils for cooling the brine are placed in a compartment at the side of the tank, and the brine is circulated through them and through the cans in the freezing tank by the propeller agitator, shown at the end. In this case the filling tank is placed above the ice dump, so that the cans can be filled as soon as they have been emptied and returned to their place in the tank. The clear ice produced is illustrated in Fig. 97. A photograph of an ice tank capable of producing 20 tons of clear ice per twenty-four hours, and fitted with high pressure air agitation, is reproduced in Fig. 98.† The air pipe runs along the wall on both sides, and is connected to the rows of cans by the flexible pipes shown. The ice produced by this tank is shown in Fig. 99, issuing from the cans on the ice dump. It is very clear and transparent, though there is a small core of opaque ice in the centre of the block.

Another ice-making plant is illustrated in Fig. 100.‡ This is interesting for two reasons, first, because the compressors are driven by suction gas engines, and secondly, because it illustrates the method sometimes adopted of using the uninsulated bottom of the ice tank to cool the ice store below.

Other Systems of Agitation. For small ice tanks a very effective method which is largely used is that of rocking the

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* Messrs. L. Sterne & Co., Ltd., Glasgow.

† Messrs. J. & E. Hall, Ltd., Dartford, Kent.

‡ Messrs. Peter Brotherhood & Co., Ltd., Peterborough.

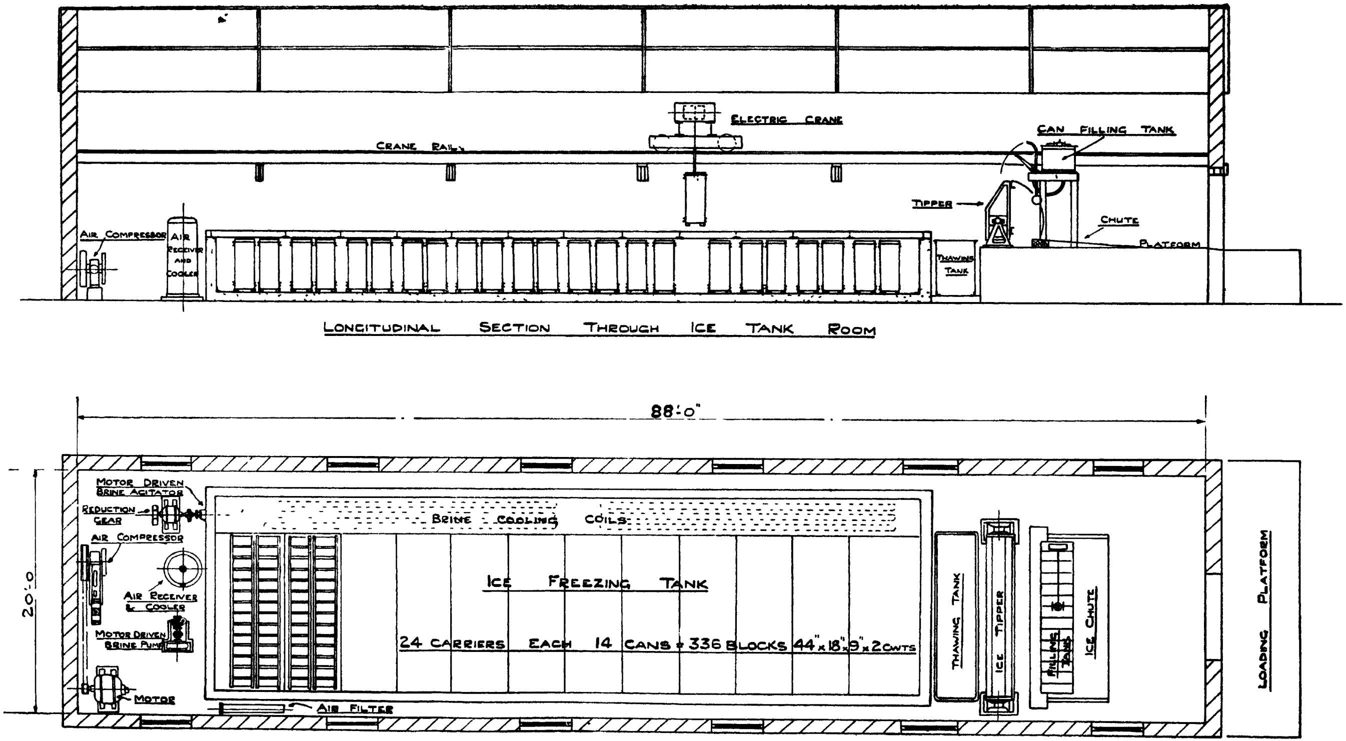

Electric Crane
Crane Rail
Can Filling Tank
Tipper
Chute
Platform
Air Compressor
Air Receiver and Cooler
Thawing Tank
Longitudinal Section Through Ice Tank Room
88'-0"
20'-0
Motor Driven Brine Agitator
Reduction Gear
Air Compressor
Air Receiver & Cooler
Motor Driven Brine Pump
Motor
Brine Cooling Coils
Ice Freezing Tank
24 Carriers Each 14 Cans = 336 Blocks 44"×18"×9"×2 Cwts
Air Filter
Thawing Tank
Ice Tipper
Filling Tank
Ice Chute
Loading Platform

Fig. 96

moulds. This has the further advantage that the rocking moulds very effectively circulate the brine, so that the necessity of any separate circulating pump or propeller is saved. The moulds are clipped together in a frame or frames, which are free to swing on a rough form of knife edge provided at each end; the rocking motion being transmitted to the frame by means of a crank and connecting rod.

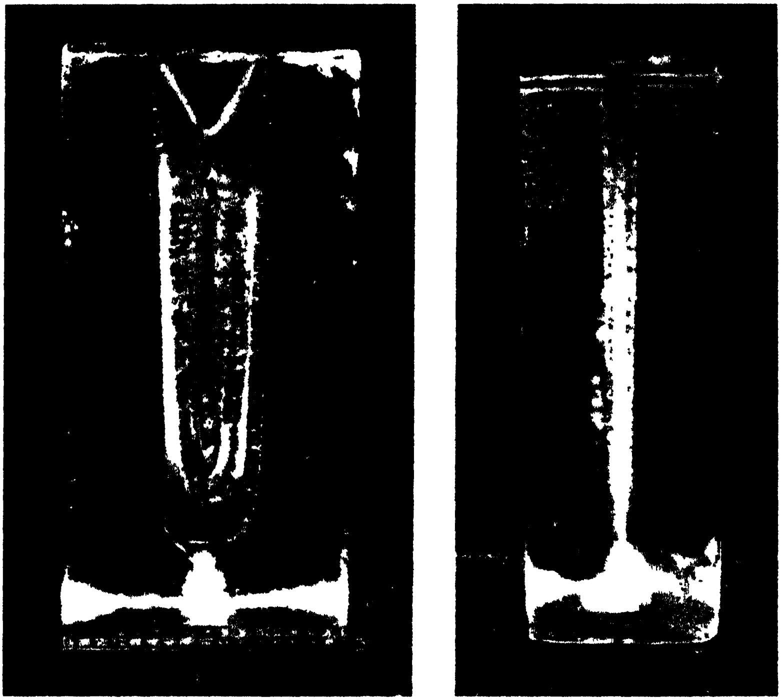


Fig. 97

While the ice produced is not so clear as that made by air agitation, it is vastly superior to the ordinary opaque ice.

A system which has been largely used is that of paddles, which are mechanically kept in motion in the moulds. The highest development of their use is seen in the ice tanks built by makers on the Continent with the 25 kilogram square moulds. The ice tanks are provided with pushing gear, which causes

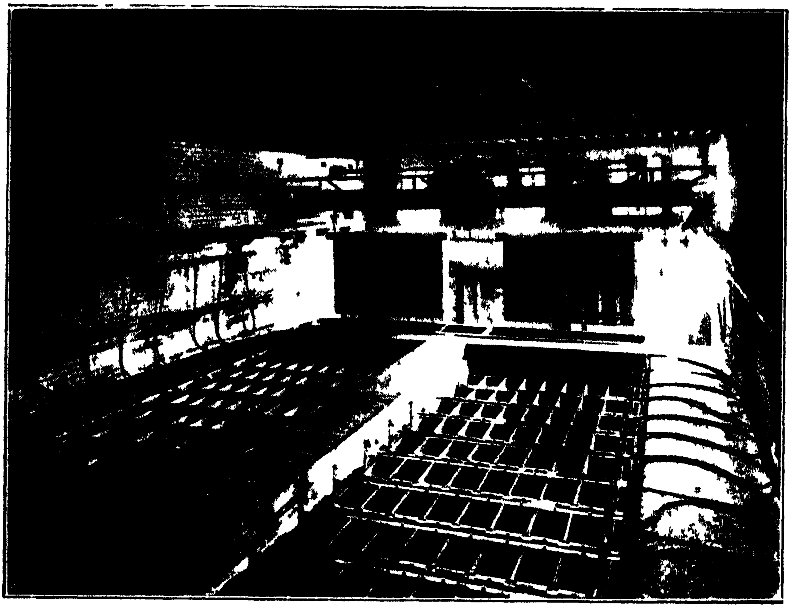


FIG. 98

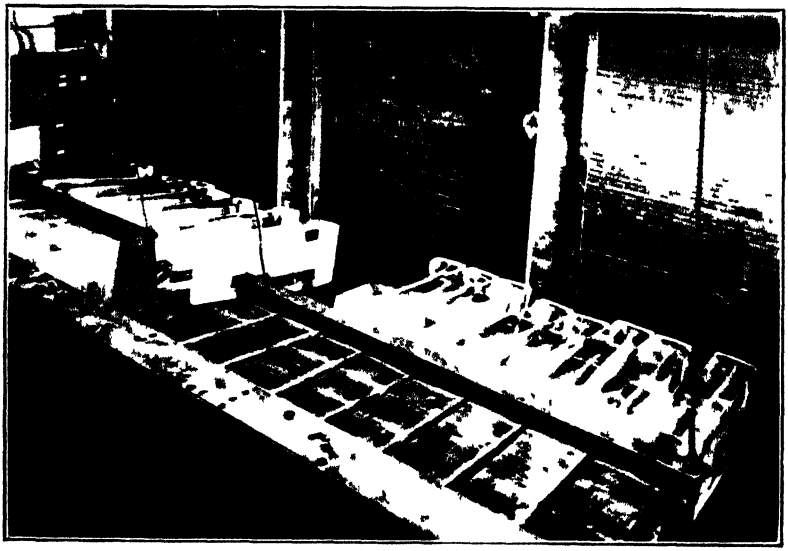
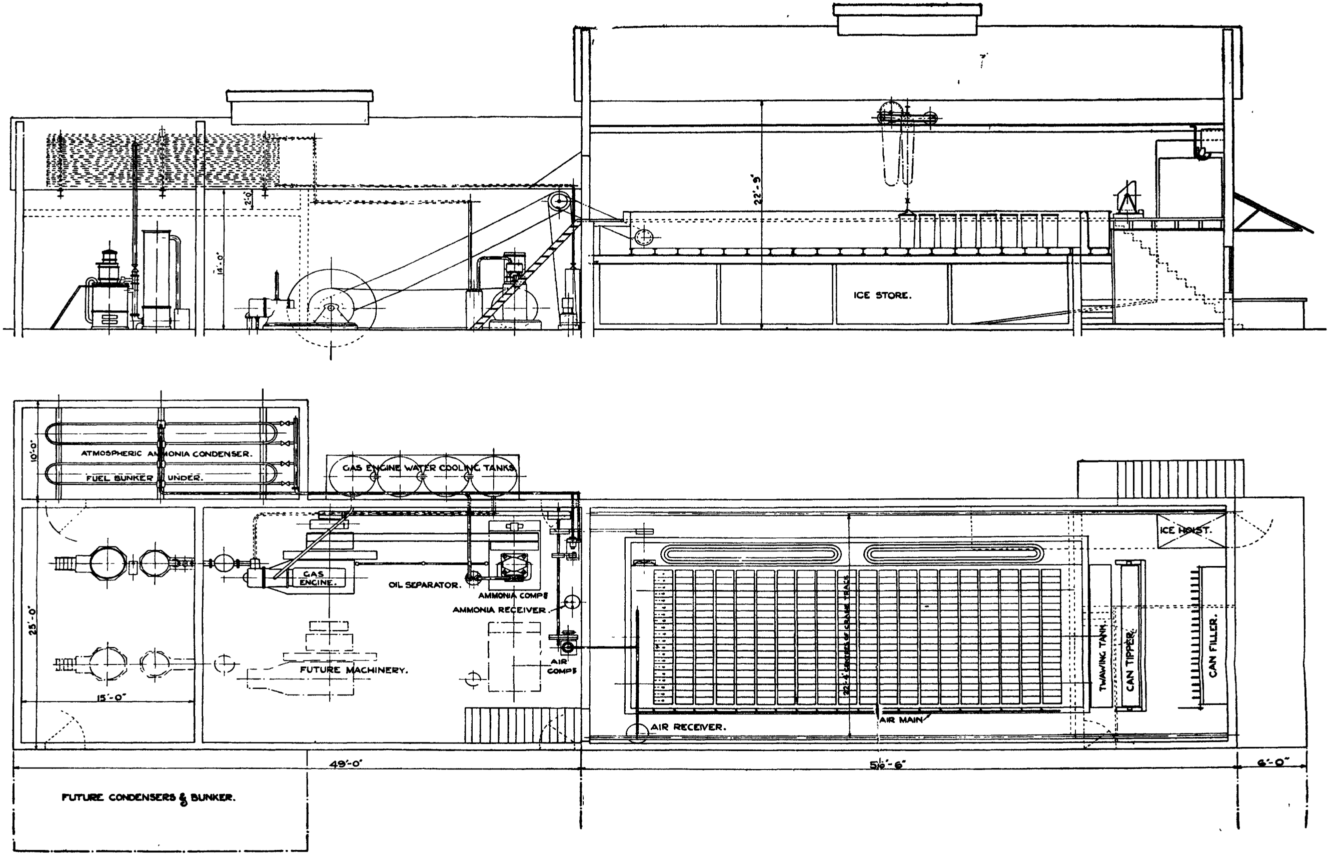


FIG. 99



(T-5179)

Fig. 100

the rows of moulds to travel forward in the tank. The operating gear for the stirring-rods or paddles is so arranged that they travel forward with the moulds. As the ice forms, and the water space becomes smaller, the stroke of the stirring rods is reduced and they are slightly raised so as to keep them clear of the ice.

At about two-thirds of the length of the tank the stirring rods are withdrawn and the centre space is left to freeze up without agitation.

The system permits extreme regularity in working, and except at the three fixed points where (1) the moulds full of water are lowered into the tank, (2) the stirring rods are withdrawn, and (3) the moulds full of ice are withdrawn, the tank-top covers are left permanently in place.

The quality of the ice is not quite so good as that made by air agitation, but with these small moulds the power required and also the first cost is considerably less.

Another system of agitation which has produced wonderfully clear ice is shown in Fig 101.* The moulds are placed in the ice tank in the usual way. Over the top of the moulds is a rocking frame which oscillates backwards and forwards, taking its motion from the prime mover by means of a belt. Secured to this frame, and in the centre of each mould, is a bronze rod, in size rather like the brass staircase or curtain rod familiar to most people. This rod moves backwards and forwards with the motion of the oscillating frame. It keeps the water in the mould agitated and washes the air off the surface of the ice as it forms. The ice forms from the sides and bottoms of the mould, and unless precautions were taken the end of the rod would soon be frozen in or broken. This is got over by an ingenious arrangement which permits the rod to rise but not to fall. As the ice forms on the bottom the rod is gradually raised in the mould until, when the water is nearly frozen solid, the rod is almost out of the mould. A block of ice frozen in this type of tank from ordinary tap water is illustrated in Fig. 102. Its clearness is shown by the ease with which the wording on the Southern Railway Co.'s notice

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* Messrs J. & E. Hall, Ltd., Dartford, Kent.

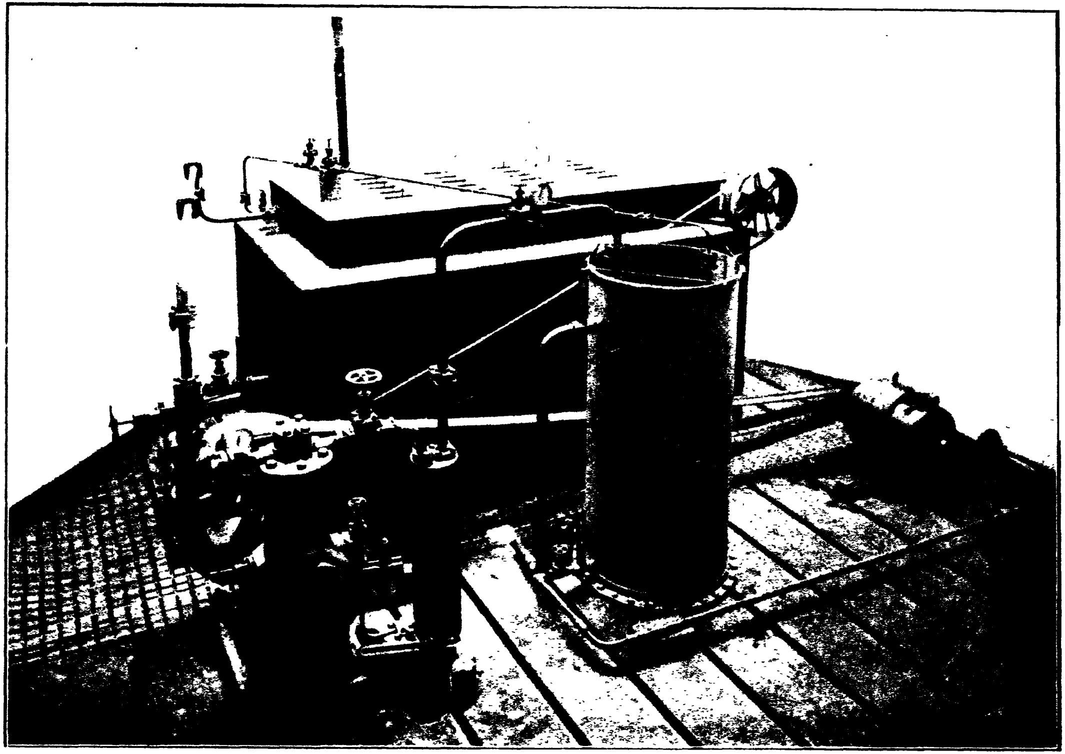

FIG. 101

can be read through the block The "T" in notice has been obscured by a patch of obscure ice, making the notice

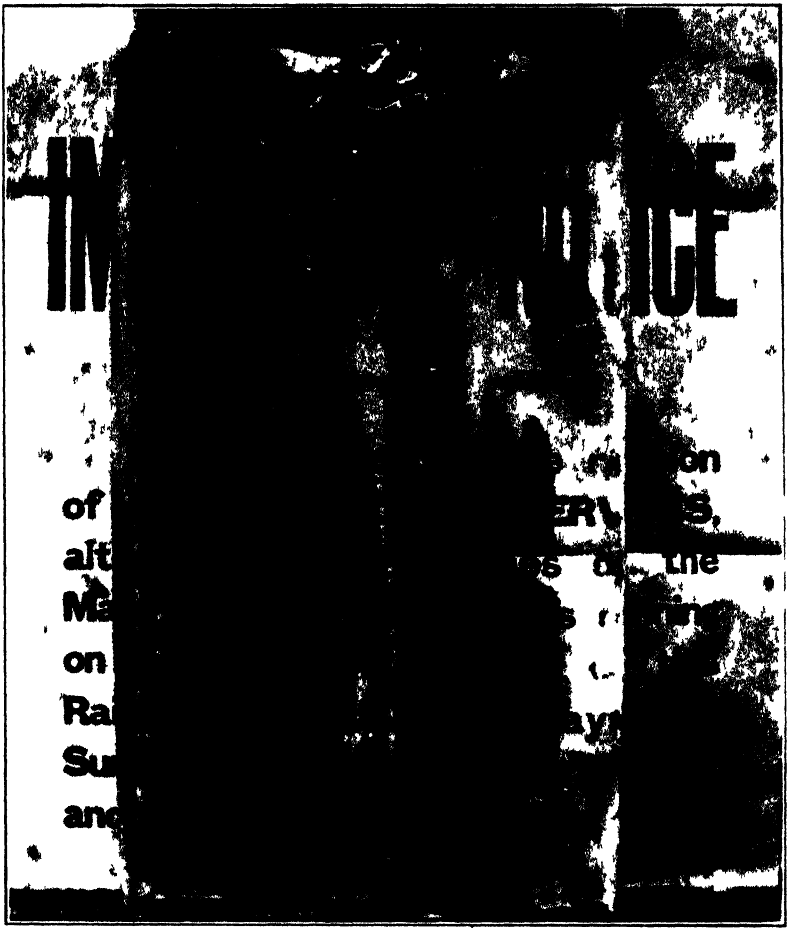

FIG 102

appear to read 'no ice,' a statement which permits of argument

In an early system of air agitation a small air pump was fitted with a differential action so that the delivery stroke was made at twice the speed of the suction The delivery pipe was connected by pipes to glass vessels shaped like a bottle and suspended over the centre of each ice can. These glass vessels had wooden nozzles which dipped into the water in the cans. On the suction stroke of the air pump sufficient water to fill it was sucked up into the glass bottle. On the delivery stroke—at twice the speed—this water was violently expelled and, owing to the velocity, passed down to the bottom of the can. The agitation thus produced thoroughly washed the surface of the ice as it was forming. In practice the cross tubes carrying these bottles were supported on wire ropes, running along each side of the tank and fixed to a rocking shaft at the back end. This shaft was provided with a counterbalance, and by rocking the lever the wood nozzles could be lifted clear of the cans when they were thrust forward by the rams.

Various other devices which do not call for special mention, such as a small propeller in each mould, have been tried on a limited scale.

Withdrawing Cores. While the agitation of the water eliminates the opacity of the ice due to imprisoned air bubbles, it does not remove the solids which accumulate and form the opaque central core.

With good soft waters the core is not of objectionable dimensions, but with hard waters it may be so, and if this is the case the ice can be greatly improved in appearance by pumping out the small central core and refilling the space with fresh water or with distilled water if especially good blocks are required.

If, for example, the weight of water removed is 7 or 8 per cent of the original water filled into the mould, and all the solids from the original volume are removed with it, the core due to these solids will be correspondingly reduced in density if the space is filled with fresh water from the same source

The cooling down of this fresh water introduces some additional work for the refrigerating machine, and also some extra labour, but the increase in power is so small as to be hardly appreciable, and with a regular routine the additional work should not involve the necessity for any increase in staff above that which would otherwise be required. This is particularly so with the low pressure system of agitation, as the cores can be pumped out and refilled when the drop pipes are removed.

Operation of a Can Ice Plant. In the operation of a can plant there are five distinct steps. These are—

(*a*) Filling the cans with water.
(*b*) Lowering the cans into the brine.
(*c*) Lifting the cans out of the brine when frozen.
(*d*) Thawing off or loosening the ice in the cans.
(*e*) Dumping the ice or emptying the cans.

When the moulds are handled singly (*a*) and (*b*) are generally combined, the empty mould being placed in its compartment of the top framing and then filled with water. When empty it will float ; as it is filled it sinks in the brine and when full should just rest on the bearers at the bottom of the tank. Owing, however, to the density of the brine, it will often be found that these moulds are floating when filled to their normal height.

In order that the brine may be kept at an even temperature and an even load maintained on the refrigerating machine, the process of harvesting the ice, refilling the cans, and replacing them in the tank should, as far as possible, be regular and continuous.

The ice tank is, almost invariably, a riveted steel plate tank, constructed with external angle iron stiffeners riveted on the sides, and stay bars across the top, as no internal staying is usually practicable. When the moulds are placed singly in the tank, the top is usually made about level with the top of the moulds when in position. When the moulds are arranged in frames, an internal angle iron is provided at each side to support the ends of the frames. The sides extend a sufficient distance above this to permit the covers resting on the top to clear the top of the moulds, as well as any hooks or attachments for agitating gear that may be on the mould frames.

With this type of tank the stay-bars across the top are often formed of inverted tee-section bars, placed between the frame spaces ; these bars also serving to locate and support the wooden covers.

When erected on site the tank should be well covered, both inside and out, with a good bituminous or other anti-corrosive paint.*

It should have an overflow pipe so that if through any carelessness in filling there is surplus brine it will merely run to waste, and will neither slop over and wet the insulation or splash into the water in the ice cans. A drain connection and valve may also be provided for convenience in emptying for overhaul or repainting, though this is so seldom necessary that the drain is often omitted, and when it does occur the brine is either pumped or syphoned out.

Construction and Sizes of Ice Moulds. The cans are made with a slight taper to enable the block of ice to readily slide out without an excessive loss in thawing, and for the same reason the sides should be perfectly plane and smooth and without any restriction at the top.

The cans are made of iron or steel plate of from 18 to 16 I.W.G. thickness and galvanized or lead coated. The seams at the sides are either welded, riveted, or folded, a band is provided round the top, the bottom plate is inverted, turned up on the outside of the mould, and riveted through the three thicknesses of metal to give a strong and solid construction where damage is most liable to occur.

Moulds are often made of black plate and galvanized when made, but while this enables mechanical soundness to be obtained, it cannot be generally recommended, as they are apt to be distorted and buckled in the process.

When moulds are made from galvanized and flattened plates, the seams should be sweated up with solder; any rivets should be flush inside and the heads both inside and out should be tinned over.

In England there are no recognized standard sizes of ice moulds. The sizes normally used by Messrs. J. & E. Hall, Ltd., may be taken as typical, and are shown on p. 259.

These are typical sizes ; the moulds can be, and are, made in any other sizes to suit special circumstances.

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* The Atlas Preservative Co., Ltd., Fraser Road, Erith, Kent, make a paint called "Ruskilla," which is particularly suitable for this work and for condensers, and Messrs. R. Walbrook & Co., Ltd., 97 Tanner Street, London, S.E.1, manufacture an appropriate paint called "Killrust."

Capacity.	Top.	Bottom.	Inside Depth.
18 lb.	12″ × 3″	11″ × 2″	2′ 2¼″
28 ,,	11½″ × 3¾″	10½″ × 3″	2′ 4¾″
56 ,,	1′ 3″ × 4⅞″	1′ 1½″ × 3¼″	3′ 1⅜″
1 cwt.	1′ 3¼″ × 7¼″	1′ 1″ × 5″	4′ 1⅞″
2 ,,	1′ 10″ × 10″	1′ 9″ × 9″	3′ 0″
3 ,,	1′ 10½″ × 11½″	1′ 9½″ × 10½	4′ 2″
4 ,,	1′ 10½″ × 11½″	1′ 9″ × 10″	5′ 8¾″

In the United States ice moulds are made in the following standard sizes—

Capacity in lb	Top		Bottom		Inside Depth.	Band Round Top.	Thickness of Plate.
50	8″	8″	7½″	7½″	31″	1½″ × ¼″	16″
100	16″	8″	15¼″	7¼′	31″	do.	16″
200	22½″	11½″	21½″	10½″	31″	2″ × ¼″	16′
300	do		do		44′	do	16″
400	do		do		57″	do.	14′

The thicknesses of the plates of which the moulds are made are here given in the U.S. standard wire gauge. On the Continent a standard 25 kilo. mould of square section is almost invariably used, and its dimensions are 190 × 190 mm. at top, 160 × 160 mm. at bottom, and 1,100 mm. deep, inside dimensions.

Time of Freezing. The diagram (Fig. 103) shows the time of freezing for various thicknesses of ice and brine temperatures.

The diagram affords a ready means of ascertaining the relations between the time required to produce certain thicknesses of ice and the temperature of the cooling brine. In the diagram, the horizontal lines represent thickness in inches of ice formed on each side of the plate or can, vertical lines represent time in hours and days, while the radiating lines represent temperature, in degrees F., of the cooling brine. The intersection of any two of these lines gives the corresponding value of the third line. For *can ice*, take half the total thickness of the ice block. With varying brine temperatures, the approximate mean temperature can be taken.

For example. To ascertain the time required to freeze plate ice of 4 in. thickness (or can ice of 8 in. total thickness)

GRAPHIC DIAGRAM FOR ASCERTAINING FREEZING TIMES* WITH DIFFERENT BRINE TEMPERATURES AND THICKNESSES OF ICE

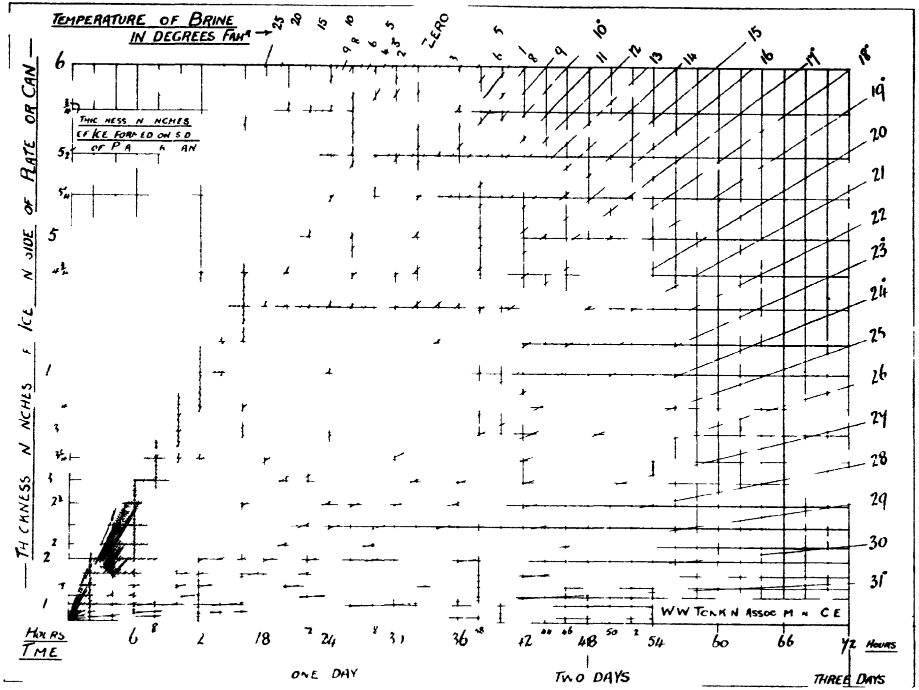

Fig. 103

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* Reproduced by permission from *Ice and Cold Storage Trades Directory*

with the cooling brine at a temperature of 23° F., follow the horizontal line marked 4 in. until it intersects the sloping line marked 23° F.; this point is seen to be at or near the vertical line marked 50, showing that 50 hours would be required to produce plate ice 4 in. thick at this temperature. Or, if 3 in. of plate ice (or 6 in. can ice) is to be made in 22 hours, the intersection of the 3 in. horizontal line with the 22 hours vertical line occurs between the two radiating lines marked 20° - 21°, showing that a brine temperature of 20½° F. would be required to get this thickness of 3 in. on each side in 22 hours. Again, in the latter case, if the brine was at a temperature of 25° F. instead of 20½° F., the sloping line of 25° F. crossing the 3 in. horizontal line at 36 hours shows the time required to freeze a 6 in. block solid at 25° F.; or, following the 25° line down to the 22 hour vertical line, it is seen that in 22 hours at 25° brine temperature, only about 2⅜ in. of ice would be formed on each side, leaving a central hollow 1¼ in. wide in the case of can ice.

These results may also be obtained by the use of the following formula -

Where H = number of hours required.
t = thickness of ice in inches on each side of plate or can.
T = total thickness of *can* ice = $2t$.
f = number of degrees F. below freezing-point (32° F.) of the cooling brine.

For plate ice $H = \frac{28 \times t2}{f}$ For *can* ice $H = \frac{7 \times T2}{f}$

For ordinary brine temperatures and thickness of ice the same results can be obtained from the above graphic diagram by mere inspection.

For can ice an allowance of from two to four hours, depending upon the size of the moulds, should be made in addition to the time as found from the diagram to cover the withdrawing of the moulds, thawing off, emptying, refilling and replacing in the tank, and cooling down of the water in the mould before the ice can commence to form.

Evaporator Piping. Ammonia evaporator coils are usually made up of 1¼ in. piping. Each individual coil should be welded up into one continuous length to avoid submerged and inaccessible joints, and should not exceed about 800 ft. in length.

Some figures on the length of piping for tanks where the coils are arranged between the moulds, are given under the heading of "Capacity Performance and Proportions of Parts."

When the piping is placed in a separate compartment, as in Fig. 96, the velocity of the brine passing over the surfaces is usually higher so that for similar temperatures and conditions of working the extent of the piping can be somewhat reduced.

The liquid supply is taken to the bottom of the coils and the return gas is taken off at the top.

Great care should be taken with the disposition of the inlet manifold and pipe terminals, to ensure an even supply of the liquid to each and all of the coils, and when the inlet terminals are made with a vertical leg to bring the manifold above the brine there should be a valve to each coil to adjust the supply.

In large tanks inlet and outlet valves to each coil are advisable to enable a coil to be shut off if repairs are necessary, without a complete stoppage of the plant, or to permit a coil being removed without undue loss of ammonia.

Temperature of Brine. In the early days of ice making it was sought to produce clear ice by freezing slowly with brine at a high temperature of 25° F. or thereabouts. The ice produced was clear, but the time taken was so great, owing to the number of moulds and size of tanks required, that the cost became excessive for any large output. In consequence, the cell and plate systems with agitation of the water were developed, but now, with improvements in the methods of agitation in can ice plants, it is possible to use brine of any reasonable temperature. As has been shown, reasons of economy point to brine temperatures of 14° to 16° average, say 15° F., as being the most suitable all round.

With very low brine temperatures the blocks of ice are liable to crack when immersed in the thawing tank, unless the water in it is at a very low temperature also. In this case the time of thawing becomes unduly protracted, with the result that the moulds are out of commission for some time.

Capacity Performance and Proportions of Parts. With ice of any given thickness the number of moulds required for a specified output, with, as a consequence, the size of the ice tank and the extent of the evaporator surface and efficiency of the brine circulation, are mutually interdependent.

The cost of power is, as a rule, the largest single item in the cost of working an ice-making plant and, of course, the higher the temperature of evaporation of the ammonia, the smaller the power required and cost of working per ton of ice made.

The temperature difference between the ammonia and the brine will, with equally efficient circulation of the brine, be in inverse proportion to the evaporator surface, so that for a fixed brine temperature the cost of working will be less with a large evaporator surface and greater with a small evaporator surface.

The lower the temperature of the brine the faster is the rate of freezing, and consequently the fewer the number of ice moulds of a given thickness required for a specified output.

The effect of variation in the proportions of the parts has been stated in a paper by Mr. Shipley, of the York Co., to be as given on the next page.

These figures are for a tank equipped with the U.S standard size 300 lb. ice-moulds, and with the evaporator constructed of coils of 1¼ in. pipe placed between the rows of moulds.

The proportions of any plant must be a compromise between first cost and actual operating costs, and as already stated the best all-round results are obtained by so proportioning the parts that the refrigerating machine can maintain a brine temperature of about 15°/16° F. with the ammonia evaporating at 5° F., and sufficient ice moulds for the required daily capacity with that brine temperature.

EFFECT VARIATIONS IN EVAPORATING SURFACE HAVE ON HORSE-POWER REQUIRED TO PRODUCE ONE TON OF ICE

(*With Single Acting Compressor*)

1. Lineal Ft. of 1¼ in. Pipe per Ton of Ice Making.	2. Square Ft. External Pipe Surface.	3. Rate of Heat Transmission, B.T.U. per sq. ft. per hr. per 1° M.D.	4. Average Temperature of Brine	5. Temperature Required in Pipe.	6. Corresponding Evaporating Gauge Pressure.	7. Total Brake H.P. per Ton Ice Making, 185 lb. C.P.
150	65	15	16° F	1·1° F.	14·85 lb.	2·661
200	87	15	16	3·2	18·1	2·468
250	108	15	16	5·7	20·0	2·352
300	130	15	16	7·45	21·5	2·279
350	152	15	16	8·7	22·5	2·218

Note. 1¼ in. pipe coils, vertically arranged between the cans and operated under flooded conditions.

EFFECT VARIATIONS IN CAN ALLOWANCE HAVE ON HORSE-POWER REQUIRED TO PRODUCE ONE TON OF ICE

(*With Single Acting Compressor*)

1. No. 300 lb. Cans per Ton Ice Making.	2. Average Brine Temperature Needed to Produce Ice.	3. Rate of Heat Transmission, B.T.U. per Sq. Ft. per hr. 1° M.D.	4. Temperature Required in Pipe.	5. Corresponding Evaporating Gauge Pressure.	6. Total Brake H.P. per Ton Ice Making, 185 lb. C.P.
10	7° F.	15	3·3° F	13.3 lb.	2·77
12	11	15	3·7	16·2	2·56
14	14	15	3·7	18·5	2·45
16	16	15	5·7	20·0	2·352
18	18	15	7·7	21·7	2·27

Note. Evaporating surface in the freezing tank assumed in this table is 108 sq. ft. or 250 ft. of 1¼ in. pipe per ton of ice.

These tables are based upon the water to be frozen being delivered to the cooling and freezing system at 70° F.

Work done by cooling system - 30 B.T.U. per lb. of ice.
Work done by freezing system 200 B.T.U. per lb. of ice.

Col. 3. *M.D.* - mean difference, i.e. the mean temperature difference between the NH_3 in the coils and the brine surrounding them.

Cols. 6 and 7 *C.P.* - condensing pressure.

The number of ice moulds to be provided is a factor of the time of freezing and weight of each block. Thus, if making 1 cwt. blocks which can be frozen solid, and the cycle of operations completed in twenty-four hours, 20 moulds must be provided per ton of ice to be made per day. If 2 cwt. moulds are used, freezing in thirty-six hours, 15 moulds must be provided per ton per day ; or if 4 cwt. moulds are used, freezing in sixty hours, 12½ moulds must be provided per ton per day, i.e.: Number of moulds to be provided =

$$\frac{\text{Output per day} \times \text{moulds per ton} \times \text{time of freezing}}{24}$$

Circulation of Brine. It is of paramount importance that the brine in an ice tank should have an even temperature throughout its length, breadth and depth, and to obtain this condition it is necessary to maintain a vigorous circulation of the brine.

With small differences of temperature there is no appreciable variation in the density. It is therefore impossible to obtain a satisfactory natural circulation and forced circulation must be resorted to. A law previously quoted in connection with condensers—Chapter VI - states that the rate of transmission of heat from a hot body to a cold one depends upon the rate at which the substance to be cooled is passing over the surface.

This law holds good for ice tanks and the better the circulation the more even will be the temperature, and to some extent the quicker the rate of freezing. With a rapid circulation, also, the rate of heat transfer from the brine to the ammonia evaporator surfaces will be high, so that the temperature difference is small and the machine can work with a higher evaporator temperature and, consequently, higher economy than when the circulation is bad.

With external brine coolers a pump, preferably of the centrifugal type, is necessary, and centrifugal pumps are largely used on the smaller ice-making tanks, but the best circulating device is a propeller running at a relatively low speed, as in Fig. 96.

When coils are arranged in the tank between the rows of moulds, the tank should have a partition down the middle, the propeller working either in an opening at one end, or in an opening in a cross partition at one end, the other end having an opening to permit the brine to circulate round from side to side.

When the evaporator coils are grouped in a separate compartment, or when a tubular brine cooler is used, the propeller should deliver the brine over or through the piping.

When this space is in the centre of the tank two propellers are generally used—one for each wing compartment containing the moulds, and where the coils are placed under a partition below the moulds, two propellers or, in very wide tanks, three or more are used.

The propeller shaft should have a gland where it passes through the side of the tank, and the gland should be extended clear of the insulation, and an outer pedestal bearing should be provided close to the driving pulley.

The propeller should be made of cast iron to avoid risk of corrosion by electrolytic action that may be set up with a bronze propeller.

Thawing-off Tank. When the cans have been drawn from the tank they are at a temperature of, say, 15° F., and the ice in them is adhering closely to the metal. In order to enable the ice to be withdrawn from the cans it must be loosened. This is done by immersing the cans in a tank, the water in which is kept at a temperature of 60° to 70° F. As the metal of the cans gets warm it thaws the ice adhering to it, and the block of ice in the can is loosened.

The water in the thawing-off tank would become so cool by the immersion of the cans full of ice that the period of thawing would become unduly prolonged if no means were taken to keep it warm. This warming is usually effected by permitting a fresh stream of water from the condenser overflow, the compressor cylinder jackets, or the main supply to enter, but occasionally the tank is fitted with a steam coil.

The thawing-off tank is made wide enough to take the full number of moulds handled at each time by the crane, and when the moulds are in rows the thawing tank extends across the entire front end of the ice-tank, as shown in Fig. 96.

The tank should have a broad white band painted on the inside to show the level of the water (when the tank is idle) that will just suffice to nicely surround the cans when they are immersed in it. If this is not done the tank may get filled too full, and the displacement of the cans will cause it to slop over and wet the insulation of the freezing tank. In any case, the thawing-off tank should be provided with a large overflow and there should, of course, be a waste-cock and a supply pipe to make up the waste, so that the tank can be emptied and filled with fresh water occasionally.

A good construction is one in which a weir is provided for the length of the tank ; the portion in which the moulds are immersed is then always full, the drain is provided to the overflow compartment, and the wide weir enables the water displaced by the moulds to escape sufficiently rapidly to prevent any overflow.

The tanks must be perfectly free internally, all staying being external, and should be wide enough to enable the moulds suspended in them to be swung gently on the supporting chains of the crane.

If the water in the tank is too hot, the blocks of ice are liable to crack and split up in the cans.

The Spray Thawer. In a system of thawing-off at one time largely used in the United States, the moulds are laid on the tipping table as they come from the tank, and water sprayed over them. The only advantage of this method is to cut out the motion of lowering the cans into the thawing tank and lifting them out again. It involves the use of a far greater quantity of water, which instead of being confined to the tank, is sprayed over the moulds as they are lying flat close to the ice tank. However carefully the drainage is arranged, it is difficult to confine the water to its proper channels and there is great risk of damaging the insulation of the ice tank.

Ice Dumps. The ice dump is one of the most simple, though one of the most necessary, portions of the plant. A handy, well-balanced dump will save an enormous amount of labour, besides increasing the life of the cans by preventing their being knocked about. Where the cans are handled singly, nothing very special in the way of a dump is wanted. A good, single-can dump is manufactured by the Triumph Co.,* and consists of a metal frame worked on a trunnion. The spray pipe is fixed round the top edge and to the bottom of the dump, and is connected to the supply by a three-way valve. The action of tilting the dump turns on the water, and when the ice has been thawed out the dump is righted and the spray turned off.

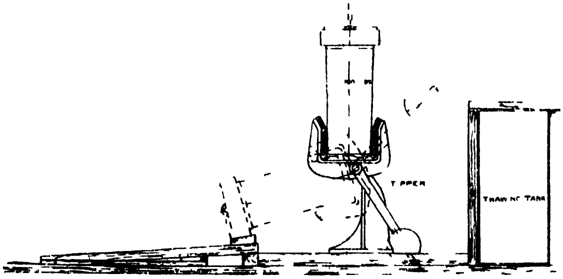

Fig. 104

A balanced dump such as is used for dealing with a large number of cans at one time is shown in Fig. 104. The cans are shown in position, being held there by the crane overhead, and the position the dump assumes when tipped is shown in dotted lines. The bottom and sides of the dump are lined with wood to prevent injury to the cans.

The action of a dump of this class is admirably shown in Fig. 105.† The dump has just been tipped and the opaque ice is just issuing from the cans, which are held in position by the traveller overhead. The photograph shows the action very distinctly.

Though balanced, it is very necessary to prevent the dumps swinging over with a rush, and for this reason the cans are placed in the dump by the crane, and the rope is gradually

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* Messrs The Triumph Ice Machine Co, Cincinnati, O., U.S.A.

† Messrs The Lightfoot Refrigeration Co, Ltd., London.

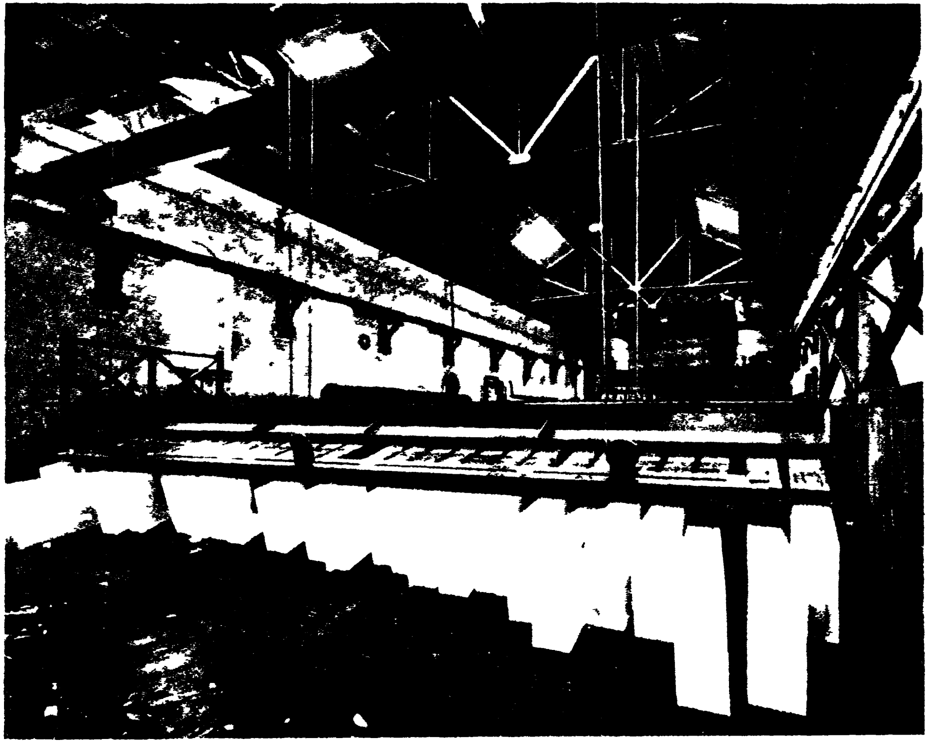

FIG 105

slacked out as the dump swings over. The dump in this way is gradually lowered into position, and the ice dumped. When relieved of the ice the dumps will either right themselves automatically, or they can be easily righted by hand. Owing to the weight they have to carry, the trunnions and frames want to be substantially built and firmly secured to their foundations.

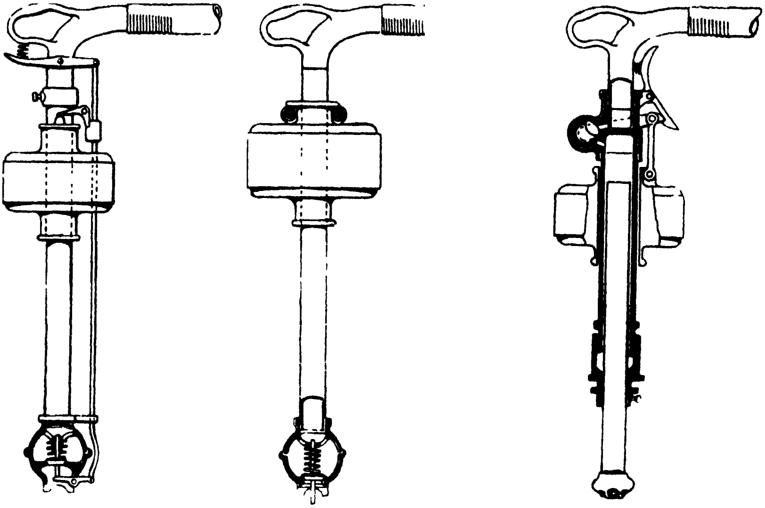

FIG. 106

Can Fillers. The type of filler used depends on whether ordinary water or distilled water is being used in the cans. If distilled water, fillers of the type shown in Fig. 106 have to be used, so as to prevent the water becoming aerated. If ordinary water is being used, aeration does not matter so much, and the filler then employed usually consists of a long, narrow tank about the same size as the thawing-off tank, but divided into as many compartments as there are cans in a frame. These compartments hold exactly a can-full. They are filled by a large pipe direct from the fore-cooler tank or, if this is absent, from the water main. From each compartment a pipe, usually connected to the tank by a flexible hose to allow freedom of movement, leads to its can. The outlet from each compartment is controlled by an ordinary draw valve connected to a common spindle and handle, so that all the compartments in the tank can be emptied and all the cans filled simultaneously. In some designs these filling tanks have the outlet to the supply pipe to the cans kept 2 in. above the bottom of the tank, the idea being to prevent any settlement that may take place being drained into the cans, a purge cock being provided for cleaning out this 2 in. of water at intervals. There is, however, no particular merit in this arrangement. If the water being used is pure there will be no settlement, and if there is settlement the sediment will get stirred up every time the tank is filled. It is not advisable to have a dead water space in which it is possible for stale water to collect. Purge cocks only add to the expense; the outlet pipes can be quite well put in flush, with the bottom of the tank, so as to draw all the water out, or fixed with a back nut in the ordinary way.

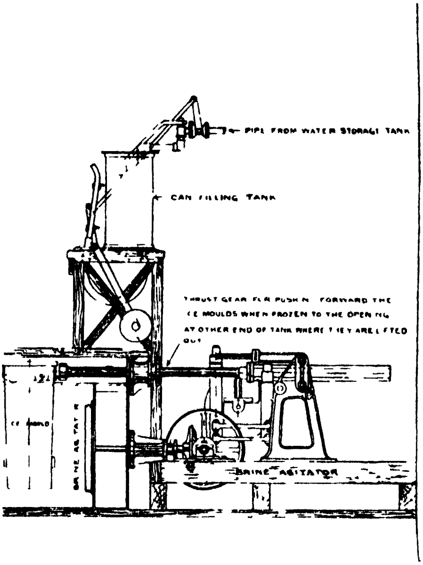
PIPE FROM WATER STORAGE TANK
CAN FILLING TANK
THRUST GEAR FOR PUSHING FORWARD THE ICE MOULDS WHEN FROZEN TO THE OPENING AT OTHER END OF TANK WHERE THEY ARE LIFTED OUT
ICE MOULD
BRINE AGITATOR
BRINE AGITATOR

FIG. 107

In order to dispense with the draw valves—in fact any valves at all—an improved form of filling tank was introduced. This is shown in Fig. 107, and consists of a number of pipes, each connected by a flexible pipe to its own compartment. These pipes are fixed, at centres to suit their cans, on a light angle-iron frame, which is attached to a rocking shaft, and is capable of being revolved through a quarter of a revolution by it.

When the tank is full the pipes and frame are raised vertically against the side of the tank as shown, the outlets being some 5 or 6 in. above the water level. On the shaft being rocked by the crane man, the pipes quickly assume the horizontal position, each pipe over the centre of its can, and empty the contents of the compartment into the can. It is important that the rocking motion should be done smartly or the water will spill, and also that each compartment should hold no more and no less than the exact quantity of water required to fill each can to its proper level. Fig. 108* shows a can filler at work filling its twenty-eight cans simultaneously. The tank behind is divided into twenty-eight compartments, one to each can, and each compartment when full holds no more and no less than the exact amount of water required to fill the can. The cans are suspended above their place in the ice tank; when full, they will be lowered into the brine and the wooden covers replaced.

The Forecooling Tank. This is a storage tank provided to hold the water passing to the moulds. It is fitted with coils of piping, which effect the preliminary stage of cooling it from its normal temperature to nearly the freezing point. The cooling is generally done by the return gas from the piping in the ice tank, which passes through the coils in the forecooling tank. This has the advantage of evaporating any entrained liquid, and ensuring dry gas going to the compressor. Sometimes a separate direct expansion coil with its own liquid supply and regulating valve is used.

The tank must be insulated on the bottom and sides, and provided with insulated covers which should be removable to give access to the tank for cleaning when required.

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* The Lightfoot Refrigeration Co., Ltd., London.

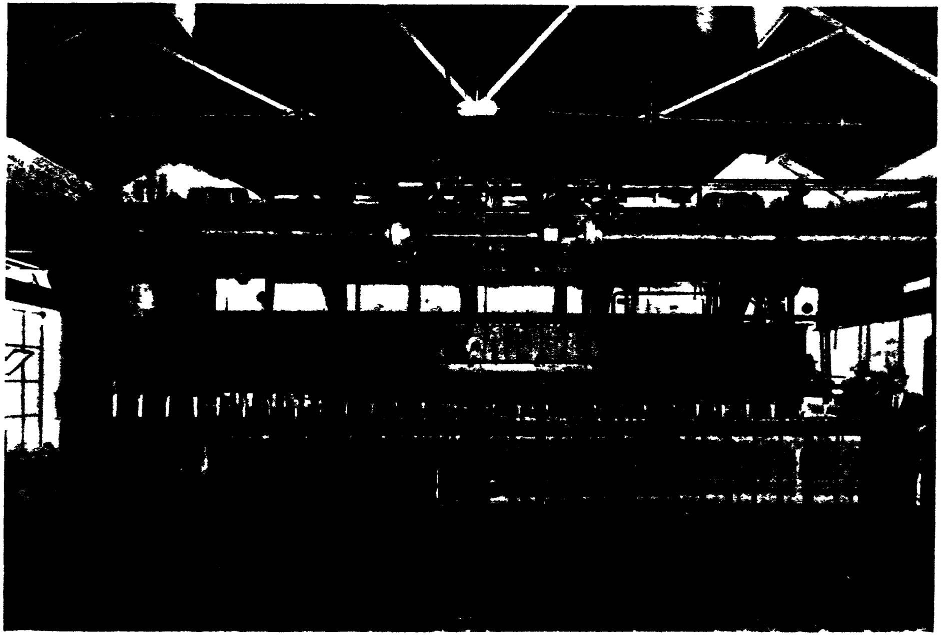

FIG. 108

A forecooling tank is of advantage when the water supply is normally at a relatively high temperature in that it reduces the total time of freezing, and prevents local heating of the brine in the ice tank by the immersion of large volumes of warm water in the ice cans.

The forecooling tank is generally given a capacity of about 30–50 gallons per ton of ice to be made per day.

Pushing Gear. The greatest regularity of working with an ice tank can be obtained when it is fitted with gear to push the whole of the rows forward for the space of one row at a time. The row of moulds frozen solid are always withdrawn at the front end adjoining the thawing tank, and always replaced at the back end.

The gear usually consists of two rams with racks engaging with pinions on a cross shaft. In the smaller tanks this is often actuated by hand, but in larger ones the drive usually has one open belt for the forward motion, and one crossed belt to reverse the direction and return the rams.

The striking gear for the forward drive is put into operation by hand, the rams automatically bringing the reverse drive into operation on the completion of their forward stroke, leaving both drives on the loose pulleys at the end of the return stroke.

With this gear the ends of the frames are provided with wheels resting on the supporting angle irons inside the tank.

With air agitation, which involves fixed connections to each row of moulds, the pushing gear cannot be used, but where it can—as in the large tanks for the manufacture of opaque ice at the fishing ports or in chemical works—it is of great advantage.

Ice Tank Cranes. A crane is a necessity for all except the smallest ice-making tanks. When the moulds are handled singly or in pairs this can be of the simplest type, consisting of a cross girder with end carriages on rails, and with lifting tackle attached to a traversing carriage on the cross girder so that it covers the whole area of the tank.

These cranes can be hand operated throughout for outputs of up to five or even ten tons per day, but for larger sizes they should have a power-driven hoist, preferably electric, but if there is no current available a pneumatic hoist is probably the best alternative.

In tanks where a whole row of moulds is handled at a time the crane must be of considerably heavier construction, and all sizes of over five tons per day should have a power-driven hoist, preferably, as before, a motor-driven one. Where current is not available, a rope drive is the most suitable for this type of crane.

When a complete row of moulds is handled at a time, the whole of the lifting gear can be fixed as no cross traverse is used, and there are generally two—or for wide tanks three or four—hoisting chains or ropes connected to a yoke bar, to which the shackles engaging with the hooks on the rows of moulds are attached. Occasionally the frames of moulds are arranged with pins for lifting, and the hooks are attached to the yoke bar of the crane.

With outputs of, say, twenty to twenty-five tons per day and over, it is advisable to arrange for a power-driven travelling motion, and where electricity is used, the two-motor type of crane is better than one in which a single motor is used to perform both duties.

In some cases the moulds are clipped together in groups of eight to ten—not in complete rows—for the full width of the tank. In these a cross traverse must be provided for the hoisting gear, and as the length of traverse, can, in any case, only be a small one, it can always be hand operated.

The Plate System. In the plate system, instead of immersing cans containing water into cold brine, the brine is circulated through flat, hollow plates or coils of piping covered on each side by flat plates to form a smooth surface, which are arranged as a series of partitions in a tank containing water.

Ice is thus formed on each side of the plate and when it has reached the required thickness is detached by circulating warm brine through the plates, the blocks of ice then being withdrawn by the crane.

Owing to the freezing being from one side only, any impurities frozen out remain in the unfrozen water. With agitation of the water opacity, due to imprisoned air bubbles, is avoided, and the ice made is beautifully pure and transparent, being fully equal to if not better than the best natural ice.

The impurities from the water accumulate in the bottom of the tank, and are flushed out at intervals.

The agitation of the water is generally effected by blowing air through it, but occasionally stirring rods are used.

As the freezing is from one side of the plate only, and as the ice is generally made in slabs of 11 to 12 in. in thickness, the freezing takes a considerable time. The average brine temperature used is about 5° F., and a week is required to make ice 12 in. thick, including the time for harvesting the ice and refilling the tank.

The tanks are generally made of 3 in. spruce. About seven or eight tanks are provided, each of which gives one day's output. They are worked in rotation to give a regular supply of ice and steady operating conditions for the machinery.

For 12 in. ice the freezing plates are spaced about 27 in. apart, and they do not extend right across the tank as room must be left for expansion. The plates are usually made about 14 ft. wide and 6 to 7 or even 10 ft. deep. The tanks are of corresponding dimensions, and each of sufficient length to accommodate the number of plates required to give the day's output of ice.

The plates are generally made of galvanized steel plate about $\frac{3}{16}$ in. thick, kept apart by distance pieces and riveted together in the form of a hollow wall; or, alternatively, coils of pipe are used with thin, flat plates on each side and riveted through. The latter construction is often preferred as it provides no dead spaces or pockets for the brine, and avoids any leakages at the rivets which must, in either case, be countersunk and flush riveted.

To harvest the ice the cold brine is turned off and warm brine from a special supply tank heated by a steam coil is pumped through the coils. This naturally drives the cold brine before it, and returns it normally to the brine cooler. When all the cold brine has been displaced the return brine (now warm) is diverted by a cock into the warm brine tank.

The ice made will adhere to the sides and bottom of the tank in addition to the freezing plate, and separate coils for warm brine are generally placed along these for thawing off.

These side and bottom coils are also useful for preventing the ice creeping across the sides and bottom of the tank and joining up two adjoining slabs, a difficulty which is liable to occur if the agitation of the water is deficient.

In some cases direct expansion is used in place of brine. Pipe construction for the freezing plates then becomes imperative and thawing off is effected by shutting off the suction to the compressor, and changing over by means of suitable valves and connections to the delivery, so that warm gas is used for thawing off and the freezing tank becomes temporarily an extension of the condenser.

While the ice produced is of exceptional quality, the first cost is very much greater than that of a can ice plant, and in order to obtain a reasonably rapid time of freezing, the brine must be carried at a lower temperature, which means an increased power for a given capacity.

The very large and heavy slabs are difficult to handle, and have to be cut up either by circular saws or steam-heated cutters, involving extra labour and wastage of ice.

The slabs or plates are lifted from the tank by means of a crane and suitable lifting hooks which are placed in position in the tank and frozen solid into about the centre of the thickness of the ice. In one design the plates for brine circulation are made portable and are themselves lifted out with the ice attached. The warm brine connections are made, and the blocks thawed off on a tipping frame or dump, which receives the blocks and lowers them into a horizontal position on the platform ready for cutting.

Fig. 109* illustrates the action of a plate tank. The general idea will be seen at a glance as the figure is self-explanatory.

A block of plate ice just harvested is shown in Fig. 110.†

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* The Frick Co., Waynesboro, Pa., U.S.A.

† The Lightfoot Refrigeration Co., Ltd., London.

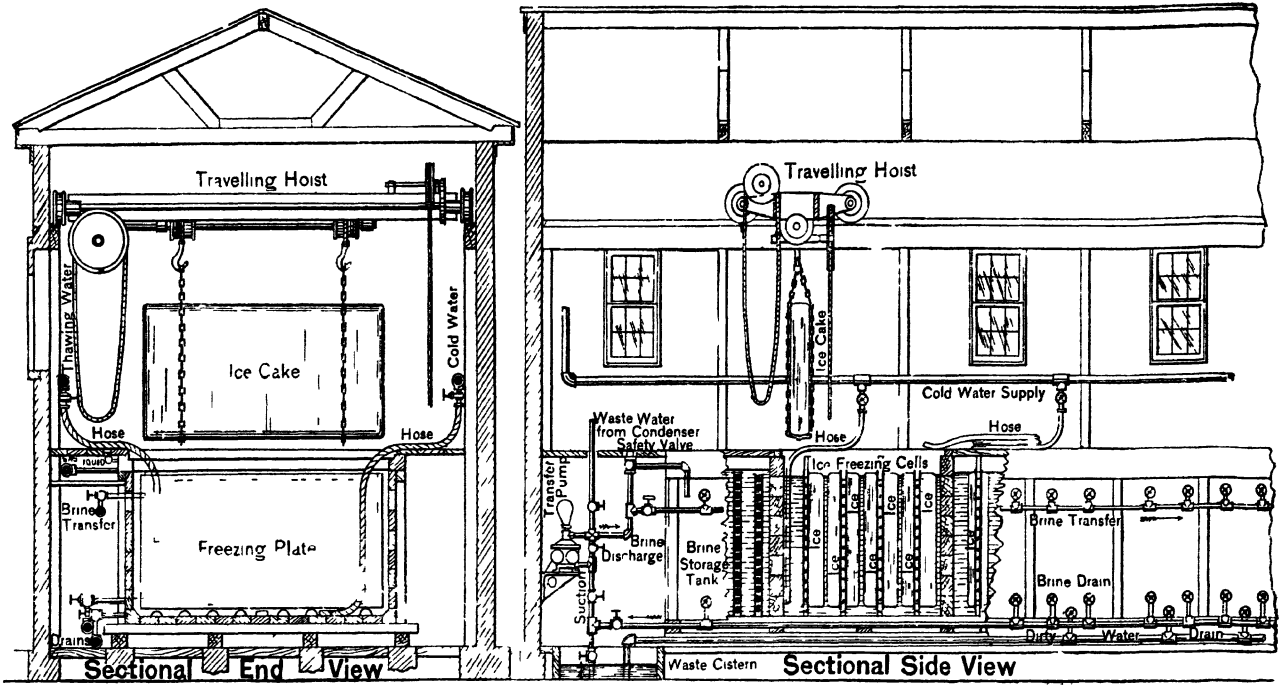
Travelling Hoist
Ice Cake
Thawing Water
Cold Water
Hose
Hose
Brine Transfer
Freezing Plate
Drains
Sectional End View
Travelling Hoist
Ice Cake
Cold Water Supply
Hose
Hose
Waste Water from Condenser Safety Valve
Transfer Pump
Brine Discharge
Suction
Brine Storage Tank
Ice Freezing Cells
Ice
Ice
Ice
Ice
Ice
Ice
Ice
Brine Transfer
Brine Drain
Dirty Water Drain
Waste Cistern
Sectional Side View

FIG. 109

The Pluperfect System. In the Pluperfect system of ice making the direct expansion of ammonia is employed and the use of brine entirely eliminated.

The ice produced is similar to plate ice in that it is made in large slabs, which are perfectly clear. The essential difference, however, is that while each plate in a plate ice tank produces two slabs of ice, each frozen from one side only, the process of freezing with the Pluperfect system is from the centre of the slab. It follows that a thickness of 12 in. can be obtained in roughly the same time that is necessary for the production of a thickness of 6 in. of plate ice.

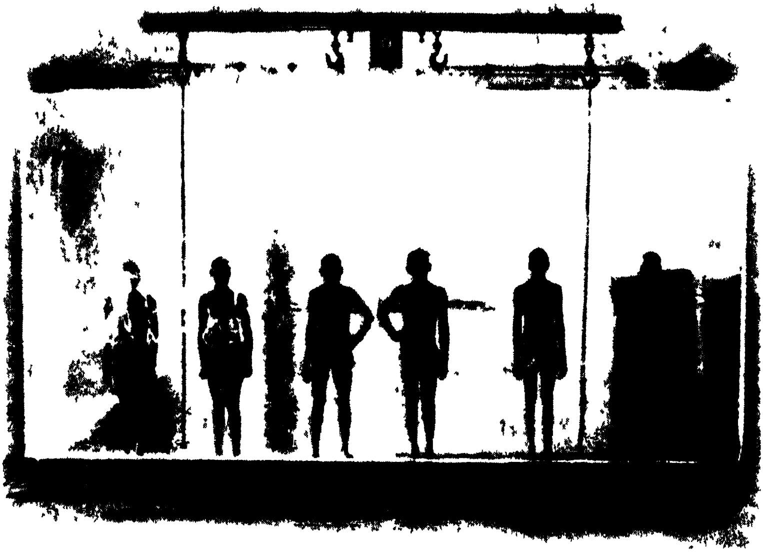

FIG. 110

The illustration Fig. 111 shows a group of these tanks in operation. The tanks themselves are similar to plate ice tanks, and the agitation of the water in them is effected by means of compressed air. The freezing element for each slab consists of a row of vertical pipes, in which the ammonia evaporates. The ice forms, in the first place, as a series of cylinders round

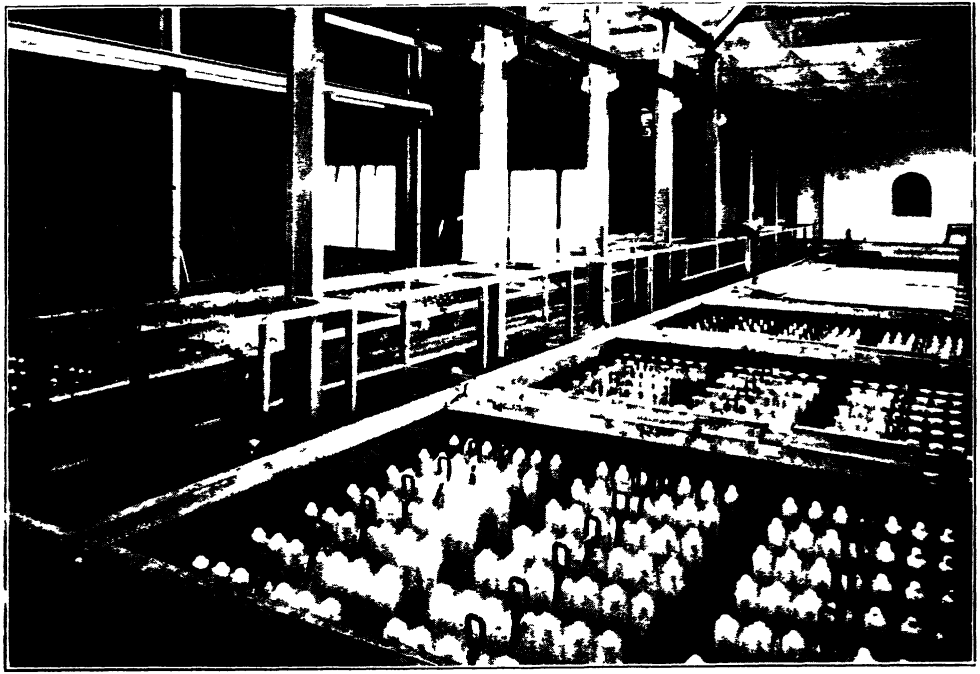

FIG. 111

each pipe, and these cylinders gradually increase in diameter until they meet and join up. At that stage the ice surface is, of course, corrugated, but as the freezing proceeds the hollows fill up, and for the usual thickness of 12 in. the surface is practically flat.

The vertical pipes are made up of two sections of D-shaped tubing welded together along their flat face, virtually forming a plain tube with a central partition. Caps are welded on to the top ends of the tubes, and act as a return bend for the gas by putting the two tubes in communication with each other. Each tube is bent so that the D-shaped tube forming the down leg of one vertical pipe also serves as the up leg of the next.

Each freezing element, therefore, somewhat resembles a rake with the prongs pointing upwards, and the ammonia passes through the whole, from the liquid connection on the one side to the return gas connection on the other side of the tank.

The process of thawing off is effected by closing the suction connection and allowing the liquid ammonia trom the condenser to flow through the piping in the tank, which is to be harvested, on its way to the remaining tanks in which it is evaporated. This has the great advantage of also cooling down the liquid ammonia.

Each tank is provided with stop valves and regulating valves, and the pipe connections are so arranged that this change over can be readily effected. A number of tanks are used, depending upon the output required, and, as in a plate ice plant, these are filled, frozen up, and harvested in regular rotation.

For lifting the ice from the tank suitable shackles for the crane are frozen into each slab. After thawing has proceeded sufficiently to release the ice from the freezing pipes the slabs are lifted straight off the freezing pipes and out of the tank. The blocks of ice have, of course, a number of small holes through them, but these are of no serious consequence and do not affect the quality of the ice.

The construction only provides a small surface for the freezing elements in which the ammonia evaporates. In order to keep the tank equipment within reasonable bounds of size and cost, it is necessary to work with a larger temperature difference between the water—about 32° F.—and the freezing medium than is necessary in a can ice plant. Consequently, while the power-required to drive the brine agitation is saved, there is no reduction in the compressor capacity or power required for driving it.

The Cell System

While the can system produces ice in tapered blocks from 3 to 12 in. thick, and the plate system in large plates about 12 in. thick and weighing several tons, the cell system, like the Pluperfect system, produces it in nearly square blocks, and as a cube practically* presents the smallest external surface for the maximum capacity, ice in this shape melts less readily than in any other.

Theoretically the cell system will produce blocks of perfectly clear ice. Actually the ice is seldom so clear as the natural product, and unless the greatest care is exercised in its manufacture, it will freeze with a core which detracts from its appearance.

The cell tank is usually made of hard yellow or Baltic white pine, the planks being bedded in hot asphalt before being bolted together by long bolts passing through them. The ends and sides are built in the same way, the sides being housed into the bottom and ends, and the whole made perfectly watertight.† The tanks can be made in any size, but usually run about 10 ft. square and 5 ft. deep. The tank is provided with a false bottom which forms the bottom of the ice cells.

A 10 ft. × 10 ft. × 5 ft. tank will contain about twenty cells, the sides and ends of which are formed of hollow iron walls supported on the false bottom. Through these walls the brine circulates, freezing the water in the cells on each side. The false bottom is pierced with a number of rectangular holes, one coming in the centre of the bottom of each cell. In addition to the false bottom there is a false side, and between this and the real side there is a space in which a paddle or plank, worked off a rocking lever by the engine or by an electric motor, rises and falls. When the whole tank has been filled with water, the brine is turned on and freezing commences. At this juncture the paddle is started and, by rising and falling in the closed space at the side, causes the water to gently flow backwards and forwards through the holes in the bottom of each cell. By this agitation the water keeps washing the freezing surfaces free from air bubbles and impurities, and allows the water to freeze clear. The agitation is continued until the water in the cell is all but frozen solid; it is then stopped, and the whole block is allowed to solidify. The water between the false bottom and the bottom of the tank is not frozen, and is drained off before the ice is harvested.

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* Actually, of course, this condition is fulfilled by a sphere.

† In some plants the planks are jointed together with thick waterproof paint, the vertical joints being made with rushes.

The thawing off process, which is a slow one, taking from two to three hours, is very much like that adopted in the plate plant, and consists of turning off the cold brine and circulating warm brine until the ice is loosened in each cell. When loosened, the blocks are lifted out of the cells by the crane, which engages with a piece of rope or an iron ring which has been frozen into the ice.

A cell plant is more costly to put down than a can plant of equal capacity, and freezing is a slow process, a block weighing, say, 6 cwt. will require eighty hours in which to solidify. For all practical purposes the cell system has been superseded by the systems of ice making previously described.

Storage and Sale of Manufactured Ice. Ice making is very largely a seasonal business, and during the summer the demand may vary very considerably, and almost from day to day with the weather conditions. It is as a rule particularly heavy at the week-end. To enable the plant to run on a regular output some ice storage space is virtually a necessity, not only to take care of the surplus production when demand is slack, but to provide a reserve to meet exceptional demands that may arise during exceptionally hot periods or on public holidays.

The question is often debated as to whether it is more economical to put down a plant sufficiently powerful to make all the ice required during the season and shut down entirely for the idle months, or to have a small plant with a large ice store and manufacture all the year round, storing the ice made in the winter and selling it in the summer when the demand is high. For a given yearly output the first method will probably involve the smaller total cost, for although the machinery itself will cost considerably more, this will probably be more than counterbalanced by the cost of buildings and insulation for the large ice store which would be necessary with a small plant.

In determining the most economical extent of the storage the question of first cost must be considered in conjunction with the actual cost of working. It is difficult to lay down any definite rules, as conditions vary very largely with climate and the nature of the demand, but as in most other matters, a reasonable compromise probably represents the soundest practice.

It is argued that a large plant can be shut down during the winter season and the men discharged so that no wages are being paid or fuel consumed, that the outgoings during this period are small, that the power required for driving the machinery is used for making ice only, that the expenditure of power required to cool the ice store gives no direct return, and that storage means double handling and consequently increased working costs. On the other hand, it is pointed out that if machinery is left idle it will deteriorate to a greater extent than if it is working and properly looked after, that when once a staff have got used to a plant and are able to handle it to the best advantage, it is unwise to discharge them and get in new men every season, that the cost of making ice in cold weather when all natural conditions are in favour of the low temperature is smaller than during the summer, and that the cost of cooling a storage room is small.

There is the further factor that the sale of ice does not entirely cease during the winter, but that although it is then very much reduced there is always some demand.

Ice making can generally be most profitably run in conjunction with a cold storage plant. In this case the rooms are frequently not fully occupied during the winter, so that ice made in the winter can be stored in the vacant space. The demand for ice (which means emptying the rooms to some extent) coincides with the demand for storage space, so that as the ice goes out produce goes in. Space of this description, which is normally used for produce storage cannot, however, be relied upon except possibly for carrying some extra winter production, and for the regular storage special insulated ice stores should be provided.

When the storage is carried out on a considerable scale it is advisable to have one main room in which the winter made supply is placed and a smaller one for daily deliveries, and to take in surplus from the day's output during the normal season.

Position and Construction of Ice Stores. In order to reduce handling the ice-making tank is generally placed on the ground level and the platform on which the ice is tipped then comes naturally at about tailboard level.

In most towns considerable excavation has to be made for foundations, and it is often convenient to build the ice store in the basement immediately below the tank. In some cases, where this arrangement is followed, the bottom of the ice tank is left bare and used to cool the store, as shown in Fig. 100, facing p. 252, thus saving insulation and piping which would otherwise be required, but while the arrangement is fairly satisfactory it is not one which can be strongly recommended, and it is better to completely insulate both the ice tank and the ice storage space and to cool the latter by means of direct expansion or brine piping placed in it. To avoid risk of damage the piping should be fixed on the ceiling or high up on the side walls as shown in Fig. 112.

While it is convenient to be able to lower ice into storage rooms, it must not be overlooked that if these are situated in a basement the ice must be lifted again for delivery, and suitable lifts or hoists should be provided.

Fig. 112

There is no difficulty in stacking ice to considerable heights, and there is no objection to doing this in an ice store, as there is no in and out traffic as in an ordinary cold storage room, but a gradual filling up during the winter and a gradual emptying during the summer.

For handling the ice either lifts or hoists can be used, and the latter are often made to uptip the blocks at a predetermined point which can be gradually raised, as the store is being filled, and lowered as it is being emptied.

In some cases overhead tracks may with advantage be secured to the ceiling of the rooms to pick up the blocks of ice as they enter the store, and carry them to the position they are to occupy.

With can ice the blocks should be laid with the big and little ends alternating in each layer so that the surface remains practically level, and the lower blocks should be placed on packing strips of timber, so that there is a space for air circulation under them.

The room for the storage of ice should be cooled to a temperature of about 25° F. It has sometimes been stated that lower temperatures are an advantage, but it is difficult to see where this lies. The storage capacity required is from 50 to 55 cu. ft. per ton of 2,240 lb. This allows for handling space, but necessitates the ice being closely packed. Generally speaking, the construction of an ice store follows the same lines as that of a produce store. Efficient insulation is a primary consideration, and the use of compressed cork slabs as an insulating material is particularly advantageous. The cork slabs forming the floor insulation should be covered with from 3 to 4 in. of cement concrete, finished with a smooth granolithic surface, and should be laid with a fall to one point from whence a drain can be taken to the outside.

Even when properly cooled there is always liable to be a certain amount of damp in an ice storage room, and on this account timber construction and loose fillings should, as far as possible, be avoided.

Transport of Ice. It is a difficult matter for manufacturers to urge the purity of their product with any prospect of being believed, when the consumer sees the ice being carted about and delivered at an hotel, his door, or the fishmonger's in a dirty wagon by dirtier men. In the method of delivery now commonly in use, a dirty pad is placed on the ground below the tailboard of the wagon ; on this the ice is dropped, and is then dragged across the road through the gutter, over the pavement, and into the shop, where, after being sluiced down with water, it is offered for sale. In the majority of cases the purity of the ice is really not affected, as any filth which gets on to it is melted off ; but the moral effect on the customer is considerable, and it would create a more wholesome impression, and probably a greater sale, if these dirty and unnecessary practices could be avoided. There is no reason why ice should not be delivered in clean wagons fitted with insulated covers. The wastage would be considerably lessened, and the ice would be firmer and would last longer.

In sending ice by rail an insulated truck should preferably be used. The best method of packing ice in an ordinary truck is to cover the bottom of the truck with a layer of clean straw and pack the blocks of ice on this with a wooden slat between them ; there should be a 6 in. or 12 in. space between the blocks and the sides and ends of the truck. The blocks should be secured in this position by timber packing, and the space between the ice and the truck should be filled with fine shavings or chopped straw, the former being much the better. Sawdust should not be used, as it pits the ice. The top of the blocks are also covered with shavings, the whole being covered with a tarpaulin.

In America it is customary with some firms to pack all ice for transport in a special straw paper. The paper is in rolls, and the ice, when packed in the car, is covered with it top and sides. It is stated that this paper only costs about 1s. 6d. per truck, and that it is of considerable benefit in keeping the sawdust, shavings, etc., used as insulation, off the ice.

When small orders are being fulfilled, the blocks of ice can be packed in bags, the ice being surrounded as much· as possible by shavings or chopped straw.

Proper tools should be used in handling ice. These consist of breaking-out bars, lifting tongs, saw, dagger, and axe. The use of the proper tools* in breaking up ice will save a lot of waste. A saw is better for this purpose than a dagger or axe, as it is not so liable to splinter the block.

Selling Ice. Ice is always sold by weight, a cubic foot at 32° F. weighing 57½ lb. Can ice is exceedingly convenient for distribution in this way. The cans are made to hold blocks of definite weight, running a definite number to the ton. This makes calculation easy, and weighing is frequently dispensed with. For wholesale trade this is quite satisfactory, but, in order to encourage the sale of ice, a retail trade should be carried on. Many people who will not take the trouble to send to the fishmonger's for ice will buy it regularly if it is brought to their door, and though the distribution is the most expensive item in a business of this nature, it is in many ways the most lucrative. Retail prices can be charged for ice delivered, and if the retail trade is encouraged and the wants of the householder catered for, a regular supply of ice becomes a necessity to him. When this happy state of affairs has been produced, definite rounds can be assigned to the various carts, and the daily delivery of ice throughout the summer becomes a matter of course as in an ordinary tradesman's business. The trouble and expense of collecting the accounts have been urged against house to house distribution. In the past this has been found to be a very serious matter, and a large amount of money has been lost both through bad debts and dishonest drivers. The trouble, however, has brought its own remedy, and in the United States, where the daily retail trade is very largely carried on, the great bulk of the ice is sold on what is known as the coupon system.

This system has the advantage that no haphazard cash sales are made by the drivers of the wagons, and the ice is nearly always sold cash in advance. If the customers are well known the same system is used, but credit is given. The coupon books are printed in various sizes with distinctive numbers, and contain in the aggregate coupons equal in number to 300, 500, 1,000, 2,000 (one ton American), or even 10,000 lb. of ice.*

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* For complete list of ice tools, *see* Catalogue of Messrs. Wm. T. Wood & Co., Arlington, Mass., U.S.A.

The rates at which the ice is sold vary, the small coupon books being sold at double the rate of the large; this is necessary in order to cover the extra cost of distributing.

The way the system works is as follows—

Suppose, for instance, that a consumer buys a 500 lb. coupon book and pays for this, say, 7s. 6d. On receiving the book he signs a receipt form, which is supplied with each book, and which is filed against his name at the office of the ice company. The actual amount of ice supplied to him daily may be only 10 lb. or 25 lb., or any other quantity; but whatever it is, the customer, on delivery of the ice, tears out of his book, and presents the driver with, coupons for the amount of ice received. The driver has started on his round with, say, two tons of ice. If it is all sold he has on his return to produce coupons for that amount. A certain definite amount of wastage is allowed him, but besides this he has to account in coupons for all the ice taken out. If at the end of the season the ice taken by the customer is less than the coupons paid for, cash equal to the value of those unused and still remaining in the book is returned to the customer, or his account is credited with their value.

The system of making the customer sign a receipt for the coupon book prevents dispute as to the number of books he has had. The amount of book-keeping and the number of bad debts is enormously reduced, and, as the drivers have not to handle cash, there is no inducement to them to return ice as wasted that has really been sold.

The coupon system has been brought to a high state of perfection by the originators.† It has been almost universally adopted in the United States, and is preferred by the customers as well as by the manufacturers. The front and back page of, and a sample sheet from, a 2,000 lb. coupon book is shown in Fig. 113.

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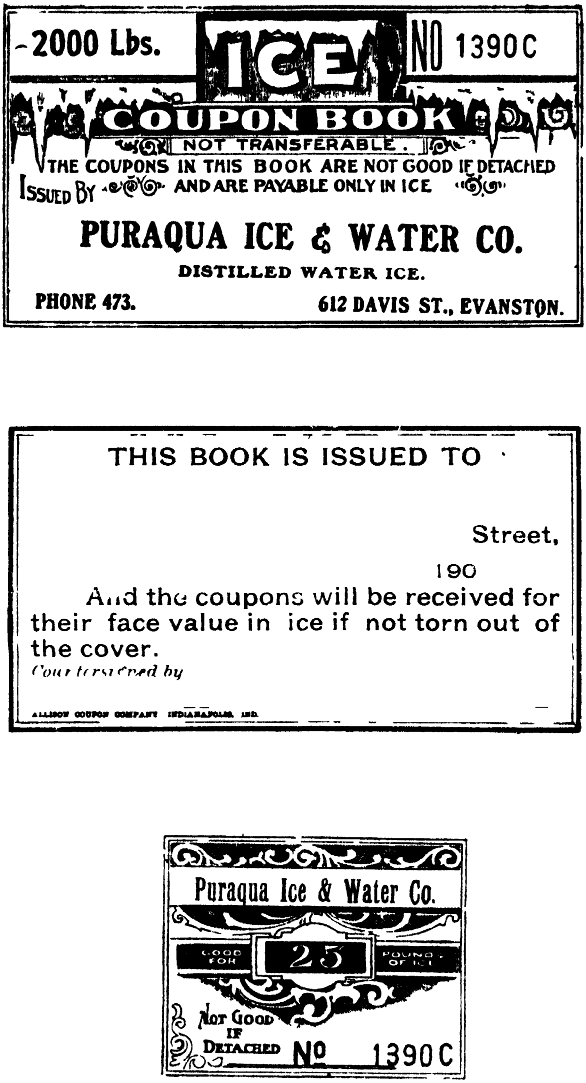
* In England the coupons would probably be made out for 560, 1,120, and 2,240 (one ton British) lb. of ice.

† The Allison Coupon Co., Indianapolis, U.S.A.



-2000 Lbs. ICE NO 1390C

COUPON BOOK

NOT TRANSFERABLE.

THE COUPONS IN THIS BOOK ARE NOT GOOD IF DETACHED AND ARE PAYABLE ONLY IN ICE

ISSUED BY

PURAQUA ICE & WATER CO.

DISTILLED WATER ICE.

PHONE 473. 612 DAVIS ST., EVANSTON.

THIS BOOK IS ISSUED TO

Street,

190

And the coupons will be received for their face value in ice if not torn out of the cover.

Countersigned by

ALLISON COUPON COMPANY INDIANAPOLIS IND.

Puraqua Ice & Water Co.

GOOD FOR 25 POUNDS OF ICE

Not Good If Detached No 1390C

FIG 113

It will be observed that the books are numbered in series on both covers and coupons. By the use of these numbers it is possible to tell the exact amount of ice each customer buys, how often he takes it, and on what days. The size of the book sold is a matter to be determined by the company ; if 500 lb., 1,000 lb., 2,000 lb. books are issued, the 500 lb. books would be numbered from 1A upwards, the 1,000 lb. books 1B upwards, and so on. In this way it is possible to tell from the detached coupons what kind of book a customer has and how much he is paying for the ice. The name and address of the purchaser and the number of the book is recorded at the offices of the ice company when the book is sold, and no ice is delivered unless a coupon is obtained at the time of delivery. If the customer is absent, coupons should be left by the ice safe for the amount of ice required.

The book illustrated above contains eight 25 lb. coupons, twenty-four 10 lb. coupons, and twelve 5 lb. coupons. Each value is printed on different coloured paper, so that it can be easily distinguished. As the coupons are collected, they are dropped by the driver into a small box secured by lock and key and attached to the wagon. At the end of the day the box is opened, the coupons counted, and the driver checked.

Solid CO_2. The use of solid CO_2 as a refrigerant is a development of the last few years, and is an entirely new factor in refrigeration. Its employment is primarily due to the rapid growth of the ice cream trade, and to the fact that the temperature of ice cream should not be permitted to exceed 5° F., which is too low to attain by the use of ice and salt. Further drawbacks to the use of ice and salt are the facts that it is messy and highly corrosive, that any accidental contact with it spoils the ice cream, and that the weight it is necessary to carry very seriously restricts the paying load that the "Stop Me and Buy One" tricyclist can carry. This last is a very important branch of the trade, and merits every consideration.

Solid CO_2 was therefore tried in the first place for the tricycle trade, and so successful did it prove that it has, in a very short time, almost entirely displaced the use of ice and salt as the refrigerant used during the transit and distribution of ice cream in all classes of vehicles.

The successful use of solid CO_2 in this direction has stimulated production, and with regular supplies available, at reasonable prices, it is being applied for many other purposes.

It is improbable that solid CO_2 will ever be produced so cheaply that it will displace the ordinary water ice for ordinary uses. It is not so much a competitor of ice as an entirely new medium for uses and processes for which ice is either entirely or partially unsuitable.

The great advantages that solid CO_2 possesses over ordinary ice for cooling purposes are the complete absence of mess and moisture, the absence of the corrosion that is inevitable when salt is added, the ability with which very low temperatures can be obtained and controlled, and the increased refrigerating effect that is provided per unit weight or volume.

The triple point for CO_2, that is the point at which it can co-exist in the three states solid, liquid, and gaseous—is 70° F., and at that temperature it has a pressure of about 5·2 atmospheres absolute. At lower temperatures CO_2 cannot exist in the liquid state, so that the solid vaporizes directly as a gas, and at atmospheric pressure has a temperature of about - 110° F.

It is this property of direct vaporization from the solid that has inspired the popular title of Dry Ice, but it should be observed that the compound word Dry-Ice is the registered trade mark of the Dry Ice Corporation of America.

The production of solid CO_2 in the form of snow can easily be demonstrated with a cylinder of the liquid, by opening the valve and discharging the liquid into a bag or a ventilated box. The drop in pressure causes partial evaporation of the escaping liquid, the heat of evaporation being taken from the remainder which is cooled sufficiently to change into the solid state.

In making this experiment some three-quarters of the original liquid escapes to the atmosphere as gas, only one-quarter being converted into CO_2 snow. Small quantities made in this way have for a long time been used for medical

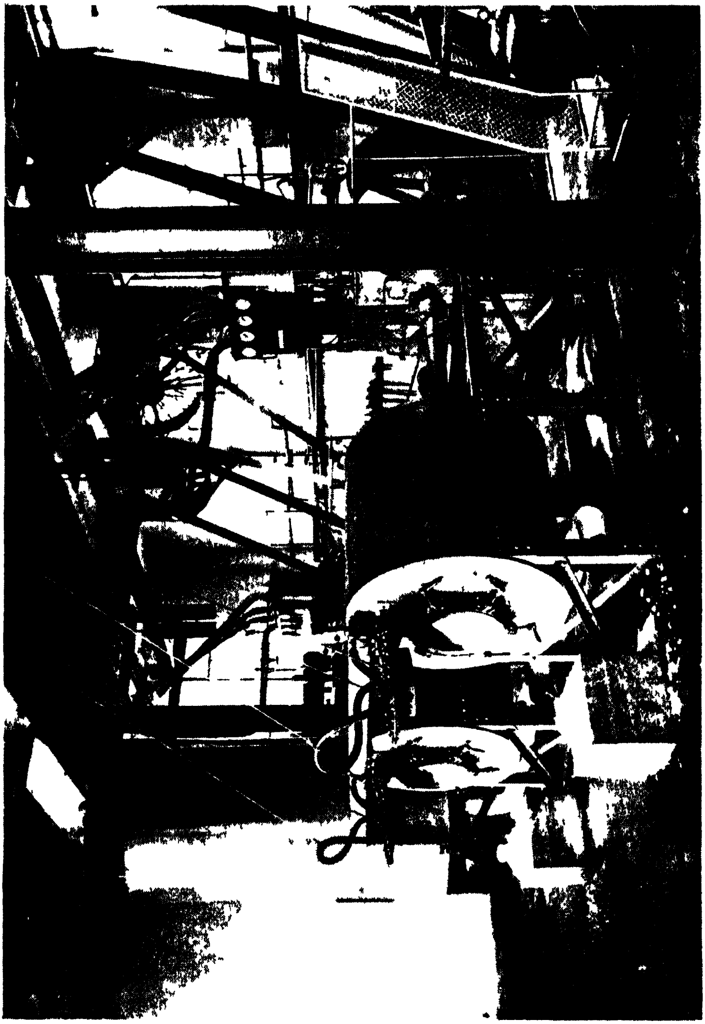


Fig. 114

and other special purposes, and were, in fact, the only practical uses for solid CO_2 before it was applied to the distribution of ice cream.

The first plants made for the production of solid CO_2 on a commercial scale worked on this principle, the soft and feathery CO_2 snow being compressed into blocks of regular size and weight by hydraulic presses.

Fig. 114* shows part of a modern plant constructed on these lines, the snow boxes being in front and the four-stage CO_2 compressors behind.

In this process, the CO_2 is produced from the combustion of coke, and is liquefied in a similar manner to that described in Chapter IV. The liquid is cooled in stages by partial evaporation to temperatures corresponding to the intermediate pressure stages of the four stage compressing plant, and is then passed through a heat interchanger before it is finally expanded through nozzles into the snow boxes.

A proportion of the CO_2 is here deposited as snow, and the remainder, in the form of gas, returns through the heat exchanger to the gasometer, from which the compressing plant draws its supply. The CO_2 gas from the generator passes into the same gasometer, and the quantity produced is adjusted to balance the weight withdrawn in the solid form.

The two snow boxes are equipped with hydraulic rams to eject the snow into the boxes, in which it is taken to the hydraulic presses for solidification. In order to obtain continuous operation the snow boxes are filled and emptied in rotation, and great care is taken with the insulation of all the parts to reduce the heat losses to a minimum.

Another system of producing solid CO_2 is that operated under the Carba patents. A diagram of a Carba plant is shown in Fig. 115. In this system the cooling of the liquid CO_2 is also carried out in stages, and an interchanger is used, but instead of using a snow box at slightly above atmospheric pressure, the final expansion is made into a receiver vessel at the triple point. The rate of admission of the liquid and of the abstraction of the gas is so regulated that the evaporation of the liquid

* Messrs. Seagers, Ltd., Dartford, Kent.

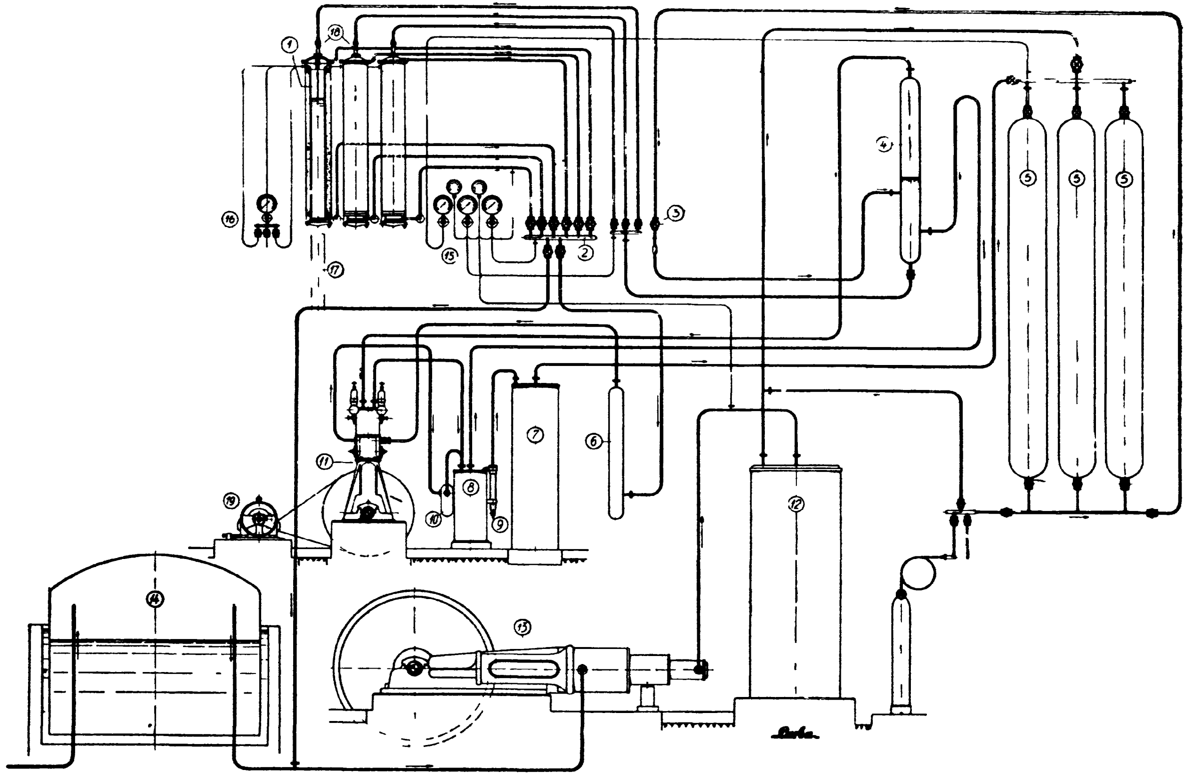


FIG. 115

to solid is only partial, resulting in an accumulation of a mixture of liquid and solid in the vessel.

When a sufficient quantity of this mixture has been accumulated a valve at the lower end of the vessel is opened, connecting it either to the first stage of the re-compressor or to the gas holder. The pressure within the vessel at once falls from the triple point pressure; part of the liquid contents evaporates to gas, abstracting the heat necessary for this purpose from the remaining contents, which solidifies, and, together with the solid previously formed, freezes into a hard dense block, which can readily be withdrawn from the receiver. No presses are required, and as a number of receiver vessels are used, which are filled and emptied in rotation, continuity of production is assured.

With the Carba system a large proportion of the solid is formed at the relatively high pressure and density of the triple point. The compressing plant is consequently smaller and requires less power than the compressing plants used when dry snow is produced at practically atmospheric pressure. The power taken to work the hydraulic presses is also saved.

The maximum density of solid CO_2 is 1,564, but this can only be obtained by employing the methods of ordinary ice making and freezing it with some colder medium. If produced it would, in fact, be too hard and crystalline for commercial use. The solid CO_2 produced as snow is usually compressed to a density of about 1·3, and that made by the Carba process has an average density of about 1·4.

The latent heat of vaporization from the solid to the gaseous state of atmospheric pressure and the temperature of – 110° F., is 246·4 B.T.U. per lb., and the heat taken up by this gas in heating to 32° F., is 28·1 B.T.U. per lb., making a total available heat absorption of 274·5 B.T.U. per lb., so that it effects nearly twice as much refrigeration as an equal weight of water ice, or nearly three times as much refrigeration as an equal volume of water ice.

In the delivery of ice cream it has been found by tests that solid CO_2 has effected the refrigeration for which it had previously been necessary to use from 10 to 12 times the weight of ice. This remarkable result is no doubt due, in part to the fact that the greater first cost of solid CO_2 has called for greater care in its use. There is, however, no doubt that its value as a refrigerant compared with ice is very considerably greater than that indicated by the figures for their relative thermal absorption due to its peculiar properties and to its harmless nature, which makes it possible to distribute and to use solid CO_2 in a more effective and economical manner.

One of the advantages of the use of solid CO_2 as a refrigerant is the facility with which the temperature can be controlled when it is used. This is effected in small apparatus by the regulation of the surface of the solid that is exposed to the air, and in larger apparatus by controlling the rate at which the warmer atmosphere circulates over the solid.

A practical example of this is shown in the cabinets designed to use solid CO_2, and illustrated in Fig. 116.*

As the rate of heat absorption is a function, among other things, of the surface of solid CO_2 exposed, the rate of heat absorption falls as the size of the block is reduced, and the temperature in the refrigerator rises.

The special feature of these cabinets is the means taken to regulate the temperature. A block of solid CO_2, usually cylindrical in shape, is placed standing on end in the top of the refrigerator. The sides and top of the blocks are covered by a vacuum flask, which is almost a perfect insulator and prevents heat being absorbed by these surfaces. The whole of the heat absorption is therefore done by the lower surface of the block, and as it is found in practice that the area of this surface remains practically constant for 90 per cent to 95 per cent of the life of the block, the heat absorbed is practically constant while there is any ice remaining.

The amount of heat which has to be absorbed by the block in a given time will depend on the volume of space which is being refrigerated and the internal temperature which has to be maintained, having regard to the external temperature, and, more especially, the effectiveness of the insulation of the refrigerator.

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* Waterless Ice Refrigerators, Ltd., Aldwych House, London, W.C.2 (Patents Nos. 319370 and 361038).

In the case of high temperature work, i.e. refrigerators having a temperature of 40° to 45° F., some insulation is required even on the exposed surface of the block, but by careful research, the amount and nature of this insulation has been so determined that any temperature between 30° F and 50° F can be maintained to within 2° or 3° F at will

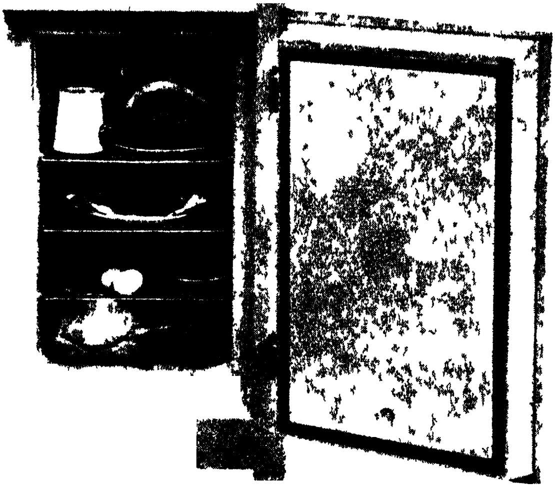

Fig 116

Other types of refrigerators are designed incorporating the principle of the vacuum flask, but modified so that any temperature can be maintained down to – 15° or – 20° F.

As is well-known, CO_2 is a perfectly harmless gas, without taste or smell. Even in small apparatus it is difficult to obtain such an accumulation as would have any effect on foodstuff or goods in storage, and, in fact, when it is desired to take advantage of the antiseptic properties of CO_2, such as in the storage of fish, the high concentration has to be deliberately fostered. In smaller apparatus the rate at which the solid CO_2 vaporizes is so slow that gas escaping into the general atmosphere of the room occasions no inconvenience whatever.

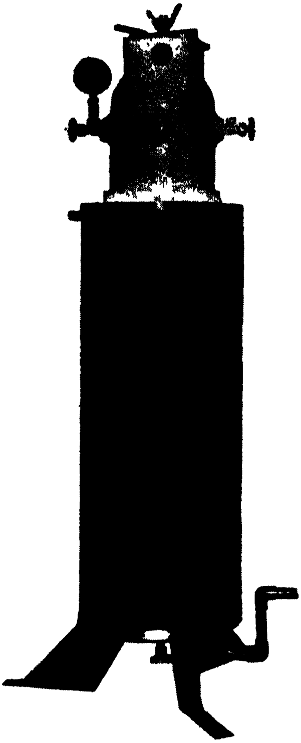

FIG. 117

Owing to the high value of the latent heat per unit of mass, and to the fact that the evolved gas forms an insulation around the block, the rate of evaporation in still air is slow, or in other words, solid CO_2 lasts for a long time despite its extremely low temperature. The loss naturally depends upon the insulating value of the containers in which it is packed, and with containers of corrugated cardboard, or similar good insulators, the loss is very small indeed. Solid CO_2 can thus be distributed over long distances with a very small loss. Its use, therefore, saves the standing charges, and the costs of carriage in both directions of the heavy and costly cylinders that are necessary for the distribution of the liquid.

There are many cases where the employment of CO_2 gas only, and not refrigeration, is required, instances of these being the aeration of mineral waters, the carbonation of beer, and as the motive power for moving beer in breweries.

On account of the very high degree of purity of the gas formed from it, solid CO_2 is particularly suitable for such purposes, and a special liquefier has been devised to enable it to be used in this way.

The liquefier - which is illustrated in Fig. 117,* consists essentially of a steel cylinder with a mouth wide enough to take the standard size blocks produced by the Carba process. It is provided with a quick action self-sealing cover that can be removed and replaced in a few seconds. When the charge of solid CO_2 is placed inside the liquefier, it will convert itself into a liquid under a pressure corresponding to the temperature, due to the transmission of heat through the cylinder walls.

About 12 hours is required to liquefy an ordinary charge of 50 lb., when the liquefier is placed in a room at normal temperature, but by using a steam jacket, the process can be enormously accelerated, and a steam-jacketed liquefier of 100 lb. capacity can be loaded and liquefied in 15 minutes.

* Imperial Chemical Industries Ltd.

CHAPTER XI

COLD STORAGE

Site for Stores. The selection of a suitable site for a cold storage warehouse is a matter requiring very careful attention. It may be taken as an axiom that the less the goods have to be moved and handled as they pass from the producer to the consumer, the better it is for them and for those who desire to make a profit out of their storage. If other considerations make it possible, it is on this account a great advantage to have the store adjoining a railway line with its own sidings. These should be brought right up to the loading platforms, so that goods can be removed from the trucks and taken straight into the cold store, or out of the cold storage rooms directly into the trucks for distribution. Whilst the goods are naturally the first consideration, rail communication will also prove a great convenience for the delivery of fuel in an engine-driven plant, and for the delivery of material and plant for buildings or extensions.

The question of cart and van space for road traffic is also most important. Ample drawing-in space must be provided for the receipt and delivery of goods without interference with the traffic in the street or on the footpaths, and if several vans are likely to be loading or unloading at a time, there should be space for one to back out or turn without having to move the others.

Most cold stores must of necessity be erected in large industrial centres where the sites available are limited, and the position depends very much upon the business that it is intended to carry on.

If a purely warehousing business is to be followed, the store must be within easy reach of the merchants and markets from which it is intended to draw, and to which it is desired to deliver, the produce stored. If, on the other hand, a distributing business is contemplated, the facilities for traffic and handling are more important, and if the store is to be run in conjunction with any other business, that will naturally have a very important influence on the selection of the site.

Other points also must be borne in mind. Refrigerating machinery requires water and plenty of it, and it is a point of considerable importance that, if possible, this water should not have to be bought.

The suitability of the ground for receiving the foundations of the buildings and machinery is very important, and before a site is definitely selected trial holes should be sunk to ascertain the nature of the strata. A rocky foundation is, of course, best but a subsoil of gravel or hard clay is very suitable. The ground should, if possible, be free from surface water, but if this unfortunately exists, it can be overcome by a damp-proof course in the concrete floor and in the walls below ground-level. Soft or unstable ground should be avoided, as piling is expensive. Concrete rafts, though a perfectly ordinary and successful method of construction, require special care in design to secure equal loading, and are better done without, if possible, on the score of expense.

Classes of Cold Stores. Cold stores may be divided into two general classes -

1. Those in which only one general class of goods is stored, a uniform temperature being carried throughout ; and
2. Those in which various classes of goods are stored requiring different temperatures, possibly in each room.

CLASS 1. The first cold stores that were built were used for frozen meat only, a uniform temperature of 22° F. being maintained throughout the building. The construction was wonderfully simple, consisting of a brick casing completely lined with a layer of insulating material, the structure of wood supporting the various floors being built inside this, and to as great an extent as possible independent of it ; the floors were laid with open joints so that there was a free circulation of air from top to bottom.

In some of these stores the only entrance is from the top. All goods entering have to be hoisted up to the level of the top floor and lowered down into the stores, while on leaving they must be hoisted up out of the stores and lowered down again. The top floor in these cases is used for sorting and distributing the various brands of beef and mutton.

One of the latest very large cold stores for meat, i.e. the Albert Dock store of the Port of London Authority, is constructed on these same general principles, and differs only in that the shell structure with the internal floors and columns is constructed in ferro-concrete and that the temperature is maintained at the now normal figure, for frozen meat, of 15° F.

The cooling of a store having one temperature throughout is also a simple matter, and is usually carried out either by direct expansion piping or by forced air circulation.

CLASS 2. It is with this class of cold store that great forethought and skill has to be shown and the design becomes more complex. The store has to be divided up into a number of rooms or sections, each insulated from the others and with the cooling appliances so arranged that there is no intercommunication of the air between the several and separate rooms or sections in which different classes of goods requiring different temperatures may be stored.

Each of the rooms must be in easy communication with the lifts or hoists, and must be internally fitted to suit the class of goods to be stored in it.

The maintenance of an even temperature for cold storage is of very great importance. It is more necessary, as a rule, that the temperature should be kept nearly constant with a small variation than that, with greater variations, the average should be correct. It is also particularly important, in the storage of those classes of goods such as eggs, chilled meat, and fruit, which require a temperature of about 30° F., that the temperature should be not only correct but consistent.

In England and in similar climates the insulation provides sufficient protection from lower outside temperatures. In climates such as Russia, Canada, and the northern sections of the United States, however, where there are in winter long periods of hard frost, it is necessary to provide means of warming up the stores to comply with the conditions of contract which stipulate that the temperature shall not be allowed to vary beyond prescribed limits. The store illustrated in Fig. 124 was of this class and means were provided to keep it warm in winter, when the outside temperature was many degrees below freezing.

The rooms containing goods that are only to be kept in storage for a short time should be situated on the ground floor, both for convenience and for the reduction of handling costs. Traffic in and out of these rooms is relatively greater, and in such a store a number of small rooms are often provided which can be let as independent storage space. These also should be on the ground floor.

A good general principle is that rooms to be cooled to a low temperature should be grouped together in the centre of the building, and more or less surrounded by other rooms carrying a higher temperature. It is seldom, however, that this can be conveniently arranged and a more usual practice, in a building of several floors, is to devote one or more floors to each of the same general temperature ranges that may be necessary. When this is done the freezing rooms are generally on the ground or first floor, and the temperatures grade upwards in the building. This, again, may be modified by the nature of the goods, and as far as possible large and heavy packages should be stored near the entrance and loading dock to reduce handling costs.

The loading platforms should be at tail-board or rail-wagon level. This provides the datum or starting line for the floor levels, and generally makes it convenient to have the bottom floor as a semi-basement to which goods are lowered.

A clear height inside the insulation of 8 ft. to 8 ft. 6 in. is usually ample in cold storage rooms for ordinary and economic stowage; a greater height cannot be economically utilized, and only adds to the space to be cooled and to the first cost without an adequate return.

Methods of Cooling. The methods of refrigerating cold stores may be roughly subdivided under two heads—

1. By placing the piping or other cooling appliances used directly in the rooms; and
2. By placing the piping or other cooling appliances in a

separate compartment external to the cold rooms proper, and cooling the rooms by air which is circulated over the cooler, or " battery," as it is frequently termed.

In those compartments for storage only, and particularly for temperatures below freezing point, the piping is generally arranged in the rooms. Where quantities of fresh goods have to be cooled down and, generally speaking, for all temperatures above freezing point, air circulation is preferable. For eggs it is a necessity and its use, even for ordinary frozen storage, is extending.

A combination of the two systems is sometimes employed, and in many cases, for general storage, would appear to be an ideal arrangement. Like most ideals, however, it involves a greater first cost than either system applied separately.

Under (1) the piping may be arranged either for the direct expansion of ammonia, or for brine circulation, and under (2) the air may be circulated by means of a fan, or a natural circulation may be induced by means of the pipe loft spray or curtain system, which is almost invariably used for chilling rooms in the American meat works.

Direct Expansion Piping. The direct expansion system consists merely of a series of coils of piping suspended under the ceilings, placed on the side walls, or both. The ammonia evaporates in this piping, absorbs heat, and thereby produces a refrigerating effect.

The inlet end of the coil is connected to the regulating valve at the liquid line, and the outlet is connected to the compressor suction pipe.

The pressure in the coils varies with the temperature required in the room, and the ratio of the pipe surface to the refrigerating power required, which may be taken as being roughly in proportion to the capacity. If the pipe surface is large, the temperature difference will be small, the suction pressure of the ammonia will be high and the economy of working will be at its maximum. The converse of course holds also.

For frozen meat a temperature of 15° to 16° F. is usually required, and in general practice the ammonia is evaporated at a temperature of about 0° F., corresponding to a gauge pressure of 15 to 16 lb. per sq. in.

The moisture from the air itself, and any moisture evaporated from the goods in store, is deposited on the pipes in the form of snow. If this is allowed to accumulate unduly, it has a serious insulating effect, so that it must be cleared off at regular intervals. In most cases it is possible to empty a room or section of a room at intervals, and then thaw off the snow by arranging cross-over connections and passing the delivery gas into that section of the piping which is to be cleared. In ordinary storage work this is not always possible, and the snow must be removed by scraping.

For temperatures at or above freezing point, any piping in the rooms must be provided with a system of guttering to catch and carry away any moisture which is deposited. This is usually effected by fixing pipe coils vertically to the walls, as shown in Fig. 118. For rooms of up to about 16 ft. in width this is quite sufficient, but for greater widths ceiling pipes must be provided also. These should be arranged not as single coils spread out over a large area, but as nests of coils arranged as far as possible over the alley ways. They can often be fixed close alongside a row of columns or the insulated casing round a beam, without interfering with the effective storage capacity. The piping usually employed is either 1¼ in. or 2 in. in diameter, the length of coils ranging up to about 800 ft. in the former and 1,200 ft. in the latter.

When there are a number of coils they should, as far as possible, be all made of approximately the same length, each fitted with its own regulating and liquid stop valve, and suction stop valves. Where both side walls and ceiling are piped it is preferable to keep them on separate circuits, so that either or both sets of piping can be used together or independently.

The liquid pipe from the condenser is often brought to a header in the engine room, and all the liquid stop valves, the regulating valves, and also the suction stop valves are placed there so that they can be under the engineer's immediate control. Where all circuits to the rooms are of approximately

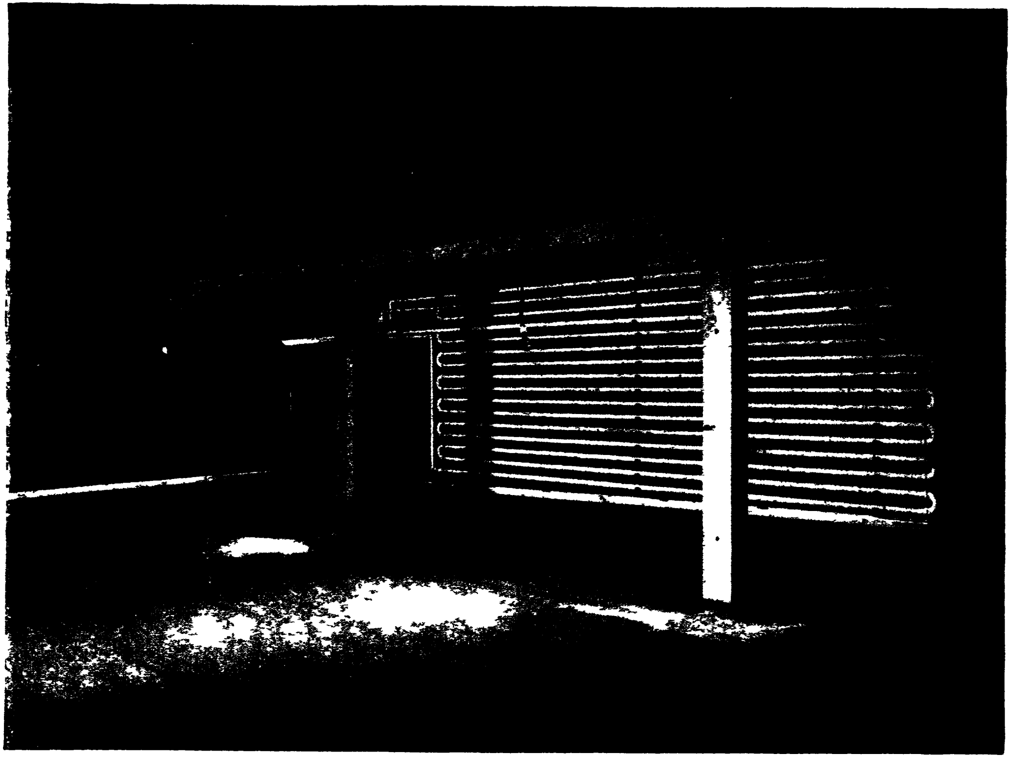

FIG 118

the same length and the rooms are on approximately the same levels, this is quite satisfactory. As a general rule, however, better results are obtained by placing the valves in the corridors or lobbies immediately outside the rooms they serve.

As the temperature depends upon the pressure, direct expansion does not lend itself to large variations in temperature. It is obvious that with several circuits in connection with each other there can be no appreciable difference in pressure, and consequently in the temperature of evaporation. Consequently, regulation can only be effected by varying the quantity of liquid passing through the different coils, which is not very satisfactory for ease and simplicity in working and adjustment. It is better, where it can be done, to vary the temperatures by temporarily cutting some sections of piping out of commission in rooms where a higher temperature is required.

Brine Circulation. In this system the ammonia or CO_2 is evaporated in pipe coils, and used to cool down brine which, in turn, is circulated through pipes placed in the various cold stores.

Care has to be exercised in placing and installing a brine system, as in addition to the refrigerating, the hydraulic side of the question has to receive attention.

The brine is generally drawn from the cooler, pumped through the pipe coils in the rooms, and returned to the cooler where it is again cooled down.

The brine delivered into the coils is all at the same temperature, but the temperature in the rooms can very easily be regulated by adjusting the quantity of brine flowing through the various coils. Nothing could be more simple or effective.

The folding plate (Fig. 119) shows a longitudinal and transverse section through a portion of a cold store fitted with brine circulation. It will be noticed that the brine flow and return headers are situated in the corridor, the flow for one floor being in the corridor below the rooms, the return being in the corridor on the same level as the rooms. By this arrangement the brine is always being pumped from a lower level to a higher level, and there is no tendency for air to get locked in the pipes.

In some cases it might be difficult to carry out this arrangement of the flow and return brine pipes, and in any case it is advisable to fit air cocks at the highest point in each circuit to avoid the possibility of air locks, unless the air can be forced out by the brine pump as is so often done on board ship.

The brine coils can be placed on the walls, as shown in Fig. 118,* or on the ceiling, or both; whereas, if the flow and return pipes were both in the same corridor, pipes could, to give good results, only be placed on the ceiling.

The flow of brine through each room can be regulated by the valves, and a whole coil can be cut out if necessary. Referring to Fig. 119, the general system of the arrangement of brine piping is as follows. The cold brine from the brine cooler enters the stand pipe *A* at *B*. This stand pipe runs right up to the roof of the building, and is fitted at the top with a dead weight relief valve, loaded to lift at, say, 12 lb. per sq. in. The overflow from the valve passes back into the brine tank through a separate pipe. This valve is provided to guard against accident, should all the deliveries be shut off at any one time while the pumps were running; in ordinary work it is seldom or never in action.

From the stand pipe the flow to each floor passes off into the headers *C*, which run along the corridors; that for the ground floor rooms is encased in the floor as shown. The cold brine leaves the headers through the pipe *D* outside the cold room, passes through the wall, through the grid of pipes on the ceiling or wall, and back to the return header *E* placed in the corridor above. The wall and ceiling coils should be on separate circuits controlled by separate valves, so that they can be turned on or off, or regulated independently of the others. Where the pipes from the various circuits enter the return header, they are fitted with a thermometer, so that the temperature of the brine can be read at any time.

The return header runs along the passage and discharges into the brine tank as shown. Each header is at this point provided with a thermometer, by means of which the engine

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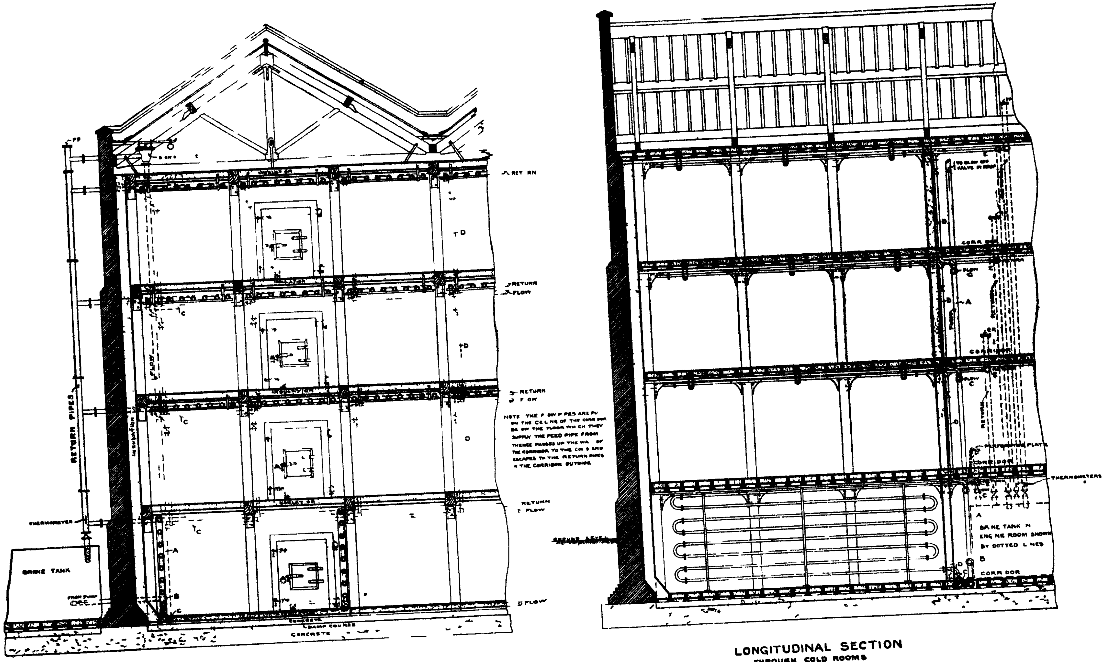
* Reproduced from *Ice and Refrigeration*, Chicago.



NOTE THE FLOW PIPES ARE PUT ON THE CEILING OF THE CORRIDOR BELOW THE FLOOR WHICH THEY SUPPLY THE FEED PIPE FROM THENCE PASSES UP THE WALL OF THE CORRIDOR TO THE COILS AND ESCAPES TO THE RETURN PIPES IN THE CORRIDOR OUTSIDE

BRINE TANK IN ENGINE ROOM SHOWN BY DOTTED LINES

TRANSVERSE SECTION
THROUGH COLD ROOMS

LONGITUDINAL SECTION
THROUGH COLD ROOMS

FIG. 119. COLD STORE SHOWING BRINE CIRCULATION

driver can see at a glance the temperature of the brine from the various floors.

It will be observed that each floor is one main circuit, and that the various rooms form branch circuits from this. The return headers passing down to the brine tank must have a perforated flange at the top of the vertical portion, or a small pipe running up above the level of the highest floor, in order to break the vacuum and prevent the brine siphoning out of the pipes. The lowest point of the system should be connected to the suction of the brine pump through a small pipe, so that the brine pipes can be pumped out at any time.

As the resistance to the flow of brine through the lower coils is less than that through the upper, there is nothing to prevent the brine pipes on the upper floors emptying through those on the lower when the pump is stopped. In the majority of plants this difficulty is overcome by fitting each main return pipe with a valve, and closing it, and the valve by the pump, when the latter is stopped. The flow of brine through the various rooms is rendered even by merely regulating the valves on the various floors. In some designs, however, the return pipes from each flow are taken to the level of the top floor and then returned to the brine tank. The former system is that most commonly in use, and it saves power, as the brine does not all have to be pumped to the highest level.

In other designs each separate circuit throughout the building returns to the brine tank, where it is labelled and fitted with a thermometer and valve. The flow of brine through any circuit is controlled from this point, more or less being passed according to the reading of the thermometer. Before the brine pump is stopped these valves are all shut off, and the brine is retained in the coils. This arrangement is very simple and effective.

Another arrangement is to use double-pipe brine coolers or to have the brine cooler and the complete pipe system enclosed with only an air vent and balance pipe, or to place the brine return tank at the top of the building, so that the brine circuit is balanced throughout and there is no danger of the brine overflowing.

It is advisable to arrange the adjoining circuits so that the brine is flowing in opposite directions; the coldest brine in one circuit being next to the hottest brine in the next. This ensures even temperatures throughout the room.

Air Circulation. In the ordinary arrangement air is blown over a cooler or battery, placed in a separate compartment external to the cold stores themselves. The coolers are generally placed at the top of the building to save space, as shown in Fig. 120.

The construction of air coolers varies considerably. The usual form consists of a series of coils of piping arranged vertically over a brine tank, somewhat similar to an evaporative atmospheric condenser. The coils are fitted with either a brine distribution trough or slotted pipe on the top. The CO_2 or ammonia is evaporated directly in the coils while the air is blown over them by means of a fan. At the same time brine from the tank is circulated over the coils by a pump. This keeps the coils free from frost by absorbing moisture as it is condensed from the air, and serves as an extension of the cooler surface.

To ensure the air passing effectively over the coils, the open spaces between them should be suitably baffled, and the circulation of brine should only be sufficient to keep the surfaces properly wetted. Excessive circulation which would cause splashing should be avoided as fine drops of brine are liable to be carried forward with the air into the rooms, and possibly deposited on the goods in them. At the same time the velocity of the air should not be too high. About 400 to 500 ft. per minute is a suitable speed, and it is good practice to fit a spray eliminator at the discharge end. This can readily be made up of two or three rows of half-round guttering, pitched rather less than their width apart and staggered, so that the gutters in the one row cover the spaces of the row in front.

The latest development of this type of air cooler is the "Cross Grid Cooler" in which, as the name denotes, the grids or coils of piping are arranged across the direction of the flow of air. This construction has been developed as the result of

FIG. 120

researches which have proved that a greater rate of transmission of heat is obtained when the air passes across the lengths of pipe than when the direction of flow is parallel to the pipes.

The pipes of a cross grid air cooler are enclosed in a riveted steel casing carried on the brine tank. This makes an enclosure which is completely air and brine tight, with the exception of the openings left at the ends for the connections to the air ducts. Doors are provided in the casing to give access to the inside.

The circulating pump delivers the brine from the tank through spray nozzles, so that the pipes are continually subject to a spray of atomized brine. As this spray fills the whole of the casing the eliminators must be of the most effective and efficient character to prevent any risk of brine being carried through. The simple type of eliminator described for the older type of air cooler is quite useless for these conditions.

Owing to the improved efficiency of the cooling surface in a cross grid cooler, the length of piping used for a given duty can be very materially decreased. The construction also enables reductions to be made both in the space occupied and in the first cost.

In some cases the air is blown over dry pipe coils, but this construction is only suitable for temperatures well above freezing point. With such a cooler used for low temperatures there would be a very rapid accumulation of snow upon the pipe surfaces, which would not only insulate the pipes but block up the area, so that the quantity of air circulated by the fan would be very much reduced and much time would be spent in cleaning the coils.

Many air coolers have been built with the cooling surface constructed of corrugated galvanized iron sheets, pitched close together and arranged in vertical stacks with brine distribution troughs at the top. The brine trickles down over the surface of the plates. A very large surface can be obtained at a low cost, and owing to the corrugations and the fact that the plates are pitched close together, the air is brought intimately into contact with the cold surfaces.

With these coolers the evaporator piping to cool the brine is generally placed in the tank beneath the stacks of plates. External coolers can, of course, be used and in some cases, notably in some of the New Zealand meat freezing works, the air battery has been constructed of vertical coils and of corrugated plates used in conjunction with each other.

Air coolers of this type have also been made with wooden hurdles and constructions similar to those used for water re-cooling towers, the object in all cases being to obtain, at a minimum first cost, a large surface over which the brine can trickle.

Air coolers are usually arranged in duplicate. It is then possible to have the refrigerating plant in two entirely separate and cross-connected sections. This cannot, of course, be done with direct expansion where piping in the rooms must be common to the two compressor units.

It is usual to arrange for one main suction, and one main delivery air duct or trunk with branch ducts, both for suction and delivery, to each of the rooms that the cooler has to serve. The delivery duct usually runs along the top of the one side of the room and the suction along the other side, as shown in Fig. 121.

It is often argued that this method is faulty and that the air, following the course of least resistance, will, in the bulk, pass through the top of the room, leaving the air on the floor relatively stagnant.

In the case of fruits, etc., which give off considerable quantities of gas, this might be serious, but all ordinary requirements appear to be met by this arrangement of the ducts.

The natural diffusion of the gases tends to spread the CO_2 in spite of its greater density. The main current may in some cases short circuit, but there will be sufficient agitation of the air and eddy flows to thoroughly intermingle the whole.

With air circulation the air in the room is very dry, and objection has been raised that this causes loss of weight and shrinkage. There is no doubt that the loss of weight is greater than in a room fitted up with pipes only, and in some cases—

notably in bacon curing—piping alone is undoubtedly preferable. As a general rule, however, the advantages of air circulation more than outweigh its disadvantages. The dry atmosphere is less favourable to the growth of moulds. There is none of the labour, mess, and inconvenience involved either in scraping or thawing snow off pipes, and in coolers using brine circulation the air is undoubtedly subjected by the brine to a washing and cleansing process, which keeps the air fresh and sweet by absorbing any odours given off by the goods in the store.

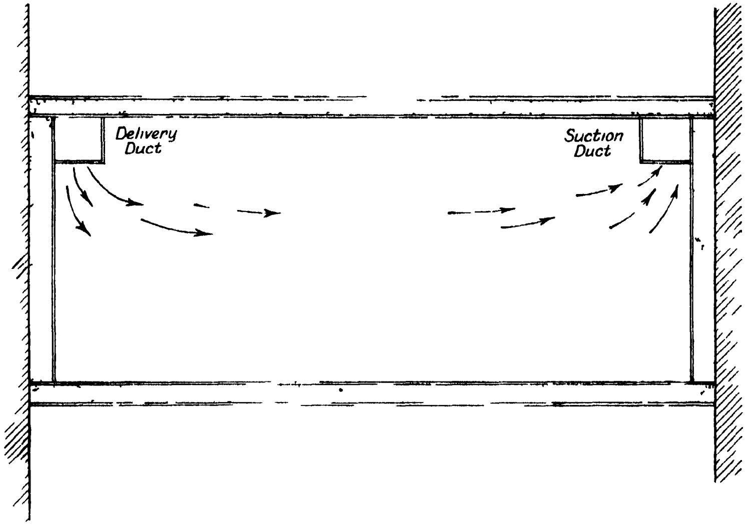


FIG 121

When brine that has been used in an air cooler is being boiled for concentration, these absorbed odours are driven off and testify their presence by their smell

Air circulation cannot, of course, be used in a store the chambers of which contain entirely different sorts of produce that might taint each other as, for instance, butter in one and fruit in another. In a large store intended for largely varied goods, the cooler may very well be of small dimensions, and used to circulate the air in some rooms only when it is convenient, and to introduce fresh and cooled air from the outside.

For ordinary cold storage rooms the fans should be proportioned to entirely circulate the air once in about three minutes. For temperatures above freezing point, once in three and a half to four minutes is usually sufficient, and in the freezing rooms of meat works, where very large power is required in proportion to capacity, the air should be circulated about once a minute.

The fans are usually of the propeller type. The spindle should be extended and the pulley or driving motor placed outside the insulated space.

Fans for circulating the air may be either of the propeller or the centrifugal cased type. With the former it is only possible to have a small resistance, and the dimensions of the ducts must be large to permit a relatively low velocity. For this reason propeller fans are now, as a general rule, only used for the smaller installations. Centrifugal cased fans are employed for larger plants, as higher velocities of flow can be obtained, and consequently the air ducts can be made of reasonable size. This is important, as it is frequently necessary to arrange ducts over door openings in rooms of restricted height, and also because space that is unnecessarily given up to air ducts does not give any return in the form of revenue.

The fact that it is possible to generate a heavy pressure or suction with a centrifugal fan is one which involves careful consideration of the speeds at which fans should be run. Cases have occurred where serious troubles in the operation of cold stores have resulted from unduly high fan speeds and high water gauges.

Fans should always be driven direct from independent motors, and wherever the arrangements of the building permit, the motor should be outside the insulation, the fan spindle being extended to pass through a sleeve or stuffing box built into the insulated wall.

Piping for Cold Stores. The best distribution of the cooling effect is obtained when piping is suspended from ceilings. The air cooled by contact with the cool surfaces falls, and the air warmed by the inflow of heat or from the heat in the goods rises so that a continuous natural circulation is maintained.

When piping is placed on the side walls only, the circulation is limited in extent. As has already been explained, side-wall piping only should not be relied upon for rooms of more than 15 to 16 ft. in width.

The actual transfer of heat from the air to the cold pipe surface depends to some extent upon the effectiveness of this natural circulation, and this is in turn governed by the position of the pipe. The rate of transfer is also affected by the thickness of the coating of snow, but for general purposes it probably averages about 2·5 B.T.U. per sq. foot of pipe surface per hour per 1° F. temperature difference.

If the sum of the various sources of heat which must be removed in order to cool a room has been determined, and the temperature of evaporation of the ammonia or the temperature of the brine to be circulated through the pipes has been decided upon, the extent of the piping can readily be determined. There is, however, almost always a considerable variation in the different factors, and it is usual to base the quantity of pipe in an empirical way on the ratio of 1 ft. run of a given size of pipe to so many cubic feet of storage space. The allowance for the larger rooms is some 7 or 8 cu. ft. per foot run of 1¼ in. piping for frozen storage, and 12 to 14 cu. ft. per foot run of 1¼ in. piping for chill room temperatures, depending on the capacity of the room and the experience of the designer.

For quite small rooms a very good rule is to fix as much piping as possible on the side walls.

An allowance for the piping to be fixed in cold storage rooms, which will give results in accordance with good general practice, can be made by taking the refrigerating power required for the room as obtained from Fig. 67, and multiplying this by the following factors—

For rooms to be cooled to .	40°	30°	20°	10° F.
Feet run of 1¼ in. piping per standard ton refrigeration .	450	490	550	630

If air coolers are used, with a positive air circulation by means of a fan or fans and with brine circulation for the outside surfaces of the piping, the length of piping in the cooler may be obtained by multiplying the length which would have to be fixed directly in the rooms by 0·4.

When other sizes of piping are used the length should be adjusted to give an equivalent external cooling surface.

Taking the two examples given on p. 150, it is found that the cold store of 50,000 cu. ft. to be cooled to 15° F. requires about eleven tons refrigeration and, multiplied by 590, this gives approximately 6,490 ft. of $1\frac{1}{4}$ in. piping to be supplied, or a ratio of about 1 ft. of piping to 7·7 cu. ft. of storage space.

The room of 1,000 cu. ft. to be cooled to 35° F. requires 0·5 tons refrigeration so that about 235 ft. of $1\frac{1}{4}$ in. piping should be supplied, or a ratio of about 1 ft. of piping to 4·3 cu. ft. of storage space. The lengths obtained in this way are calculated on the normal rates of heat transfer, and based on the refrigerating power required per twenty-four hours, and should be taken as minimum quantities.

It is obvious that the piping should be proportioned to the capacity of the machine actually installed, but to do this working on similar temperature differences would increase the length of piping to an extent that would seriously affect the cost and be more than practice proves to be commercially necessary. The figures may, therefore, be recorded as purely arbitrary ones which, used in conjunction with the refrigerating powers obtained from Fig. 67, will give satisfactory results, and approximately the best compromise between first cost and efficiency in working. The relatively smaller length of piping on the small rooms, where the hours of working are normally short, will be compensated for by the increased capacity of the machine. The figures apply to direct expansion piping whether placed in the rooms or made up as an air cooler.

If the refrigerating machine is used for cooling brine which is in turn used for cooling the air, it is obvious that the temperature of evaporation of the ammonia must be reduced if the cooling surfaces remain constant.

It is usual to proportion a brine cooling evaporator so that the mean temperature difference between the brine and the ammonia is about 10 to 15° F., and it will be seen from Fig. 65 that a reduction of 10° F. in the ammonia temperature reduces the actual output of any given compressor by approximately 25 per cent. It will be found that the greater ease of regulation with a brine cooler balances this reduction to some extent, but with a brine cooler and brine piping the machine should either have about 10 per cent greater capacity or the piping should be increased in length by about 10 per cent, or a compromise may be made by increasing both the capacity of the machine and the length of piping by about 5 per cent.

In many cases either the refrigerating power required or the extent of piping, or both, can be reduced ; thus in an ice storage room used with an ice-making plant, there is very little more than the transfer of heat through the insulation to take care of, and the same holds good for a frozen meat store, where the meat comes in directly from ships' holds or from the freezing rooms of a meat works.

Air Locks and Lobbies. An entrance lobby or air lock with two properly insulated doors used to be considered a necessity for any cold storage room, and properly used, such an air lock is, of course, an advantage in preventing loss of cold air. Only too frequently, however, both doors are left open to give a straight through passage, and the utility of the air lock is lost and extra labour is involved in opening two doors.

When an air lock is constructed it should not be made so small that there is any difficulty in opening the inner door with a truck or load of goods, as well as a man inside the lobby, after the outer one has been shut. Such an air lock is often useful as providing a moderately cooled space in which goods can be left for ready use without entering the cold store itself.

An air lock is particularly useful for moderate and smaller sized rooms.

With large stores, where there is a considerable amount of trucking and handling heavy goods, an air lock should never be considered The best arrangement for preventing escape of cold air from such rooms is to have a light enclosure inside the main door with light, double swing doors, which can be easily pushed open by a man with a truck and which will be self-closing behind him.

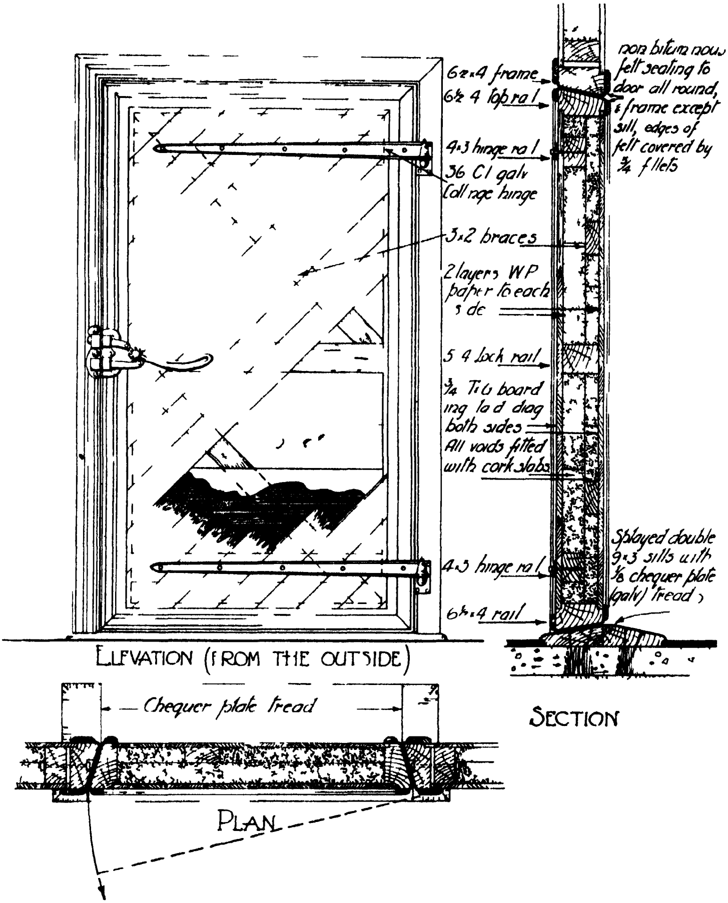

6½×4 frame
6½ 4 top rail
4×3 hinge rail
36 C I galv Collinge hinge
3×2 braces
2 layers WP paper to each side
5 4 lock rail
¾ T&G boarding laid diag both sides
All voids filled with cork slabs
4×3 hinge rail
6½×4 rail
non bitum now felt sealing to door all round, & frame except sill, edges of felt covered by ¾ fillets
Splayed double 9×3 sills with ⅛ chequer plate (galv) tread
ELEVATION (FROM THE OUTSIDE)
SECTION
Chequer plate tread
PLAN

FIG. 122

Doors A cold storage door should be airtight when shut, efficiently insulated, and easily opened and closed

Frequently, hatchways are provided either in the main doors or in the corridor for the passage of small articles. They are very convenient and minimize labour and the escape of cold air. When placed in a main door, however, they rather interfere with its proper construction and bracing.

The door-sill should be constructed to allow trucks to pass directly into the room. The sill itself should be of hard wood, and preferably protected by a steel plate put on with screws, so that it can readily be renewed when worn.

Compressed cork slabs are generally used for insulating doors. Their solid form and the fact that they completely obviate any risk of settlement being a great advantage.

Door hinges and fasteners should be galvanized and of heavy pattern, and the hinges should be capable of adjustment so that any sag which may develop can be taken up.

Except in the case of very small rooms or cupboards, door fasteners should be operated from either side to prevent men being accidentally shut up in a room. They should not only close the door tightly, but should also ease it off its seating when opening.

Doors should work easily, and it is probably best in most cases not to make them too thick. Great thickness involves great weight with a liability to sag and added labour in opening and closing. A door which is light and easily worked will often be shut (as it should) when a heavy or stiffer one will be left open. The resulting loss of cold air will represent considerably greater refrigerating power than that which would be lost by the less efficient insulation of the lighter door.

Doors can easily be tested for tightness by closing them on slips of paper placed round the jambs. These will, of course, be gripped where the door is fitting, but if the slips on either side—top or bottom—can be readily drawn out when the door is closed, it is obvious that some adjustment is desirable.

An insulated door is shown in Fig. 122.

Brine Tank and Brine Pumps. The brine tanks containing the evaporating coils can be of the ordinary oblong pattern as in ice making, but in order to save room it is usual to make them similar to the submerged condenser, the brine surrounding the evaporating coils, which are contained in a vertical circular wrought-iron tank.

When the brine circuit is enclosed a shell type of cooler is generally the most convenient type to use.

Any suitable type of pump may be employed for circulating brine. Centrifugal pumps are the type generally used, and these have the advantage that they can conveniently be direct coupled to their own driving motors.

Independent steam-driven pumps should be avoided, for with the relatively small pumps the steam consumption is always large and wasteful.

Lifts and Conveyors. In a large dockside store for the reception of chilled or frozen meat, the usual practice is to construct either the upper floor or an intermediate transit shed as a refrigerated sorting room. In such a case, where large quantities of similar articles have to be transported between fixed points, such as a ship's hold and the sorting floor, a conveyor system has many advantages, but it is probable that that is about the limit of its useful application in ordinary cold storage work.

The bulk of the stowage in cold storage rooms must of necessity be carried out by trucking and hand labour.

One of the most important—if not the most important—factors in successful cold store design is the provision of proper facilities for economical handling of the goods. For the ordinary inland store it would seem more than doubtful whether the small saving in refrigeration which can be effected by having all openings at the top is compensated for by the greater labour involved in the double handling of the goods.

As trucking is essential for the distribution of goods in the rooms themselves, the best method of handling appears to be to get the goods out of the wagon in which they are brought straight on to the truck, and to use lifts for elevating these trucks to upper or lower floors. The lifts should not be placed in the stores themselves but in a handling space arranged on each floor immediately above the loading dock. These handling spaces on each floor should be of ample area to allow for traffic. There is always a temptation to reduce their size in order that the capacity inside the insulation which is a dividend earning space may be increased. While it is important to keep the insulated space as large as possible, the outside handling spaces must not be reduced to such an extent that in and out trucking traffic is impeded, otherwise the additional cost involved by delays in handling may more than off set the extra revenue that can be obtained from the storage capacity.

Humidity in Cold Stores. The correct humidity of the air is undoubtedly of importance for the cold storage of provisions, though there is an almost entire absence of definite and reliable data on the effects of varying degrees of humidity on the appearance, quality, and keeping properties of the varying classes of goods kept in cold stores.

A high degree of saturation is undesirable, as with small variations in the temperature of the air there would be a deposition of moisture on the goods, which would adversely affect their condition and provide a favourable state for the growth of moulds.

If, on the other hand, the air is too dry, its capacity for moisture will be great, causing evaporation from the goods stored. In this way not only unduly drying them but causing loss of weight with a corresponding drop in value.

It would appear probable that for general storage purposes the most suitable condition for the air is a humidity of from 75 to 80 per cent, which is normally attained in the ordinary working of a cold store, and that for successful storage the maintenance of the degree of humidity within small limits is second only to the maintenance of a constant and steady temperature.

Buildings. One of the principal objects in designing a large cold stores is to obtain the greatest cubic capacity for the minimum wall area. By this means not only will the amount of insulation, which is an expensive item, be reduced and so first cost saved, but as the best insulation is imperfect, it is very necessary, from the point of view of reducing the refrigeration required, and thus promoting economical working cost, to have the minimum wall area through which heat can pass from the outside air into the cold stores.

Cold storage buildings are essentially of the warehouse class. They should not be overburdened with architectural features, as these only increase the expense and add nothing to the revenue. Modern cold stores, of the best design, are built exclusively of fireproof materials. With this construction not only is it possible to obtain larger areas on one floor level if these are required, but insurance rates, depreciation, cost of maintenance—all revenue charges—are reduced to the minimum. With properly designed insulation, which is possible in a fireproof building, vermin cannot find a lodging and are practically not existent.

Timber Construction. In Russia and certain other localities in the Dominions, and oversea countries, fireproof construction is not always possible, as the materials required are difficult to obtain, while timber is plentiful and cheap. In this case stores have frequently been constructed of timber, as shown in Fig. 195 (page 528). In some cases the outside walls are covered with weatherboard, and the spaces between the studs are filled with insulation, this being constructed in the usual way with double matchboarding and waterproof paper.

A good deal of care must be exercised in the class of timber used. Where this is exposed to the air and free from damp the selection is large and practically any good class of building timber will stand up to the work, but where joists or studs are buried in insulation, whether it be granulated cork or pumice, a certain amount of dampness is, at some time or another, practically inevitable, and some timbers will not stand even this.

A considerable amount of trouble has been caused by the use of Oregon pine for cold storage construction, and this timber should be avoided unless it is constantly exposed to the air. The life of ordinary timber can be increased if it is treated with certain preservatives before being placed in position. Those preservatives with a tar basis, such as creosote in its various forms, should be avoided when there is any chance of the characteristic odour being conveyed to the goods in store, but there are other preservatives, such as "Atlas"* or

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* The Atlas Preservative Co., Ltd., Erith, Kent.

"Toritna,"* which are odourless and harmless to goods stored. If these are used they should be ordered coloured. The coloured solution may cost a little more than the colourless, but if it is used it is possible to see whether the fluid has been properly and regularly applied.

In buildings of this class it is important that the timber posts should be of large size, 10 in. × 10 in. or 12 in. × 12 in., according to the weight to be carried.

The floor beams and joists and flooring should also be equally generous in size, the object being not so much strength as fire resisting qualities, for thick timber will char but will not easily burn, and a fire once started can often be put out before it gets a serious hold.

The partitions should be quite independent of the structure, and should be formed between the main posts on which the floors are carried. If the alternative is adopted, and the floors are carried on the partitions, structural alterations will be difficult and the structure generally will be less stable and efficient.

Fig. 123, which shows a building designed by the author for erection in Russia by Russian workpeople, illustrates this type of construction. In this case the outer walls were of brickwork. Buildings of this class are termed fire resisting as distinct from fireproof.

Ferro-concrete Construction. Buildings constructed of ferro-concrete are popular in the United States for cold storage purposes, and have been erected in this country to some extent. While ferro-concrete is of the greatest possible value for foundations and for structures like bridges, dams, and wharves, which are likely to remain unaltered until they are finished with altogether ; industrial buildings for whatever purpose they may be designed are liable to be altered as time goes on, new methods are adopted, and new processes come into use.

The amount of alteration which can be made to a ferro-concrete building without affecting its stability is limited, and

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* The Dry Rot and Fire Prevention Co., Ltd., 30 King's Road, St. Pancras, London, N.W.1.

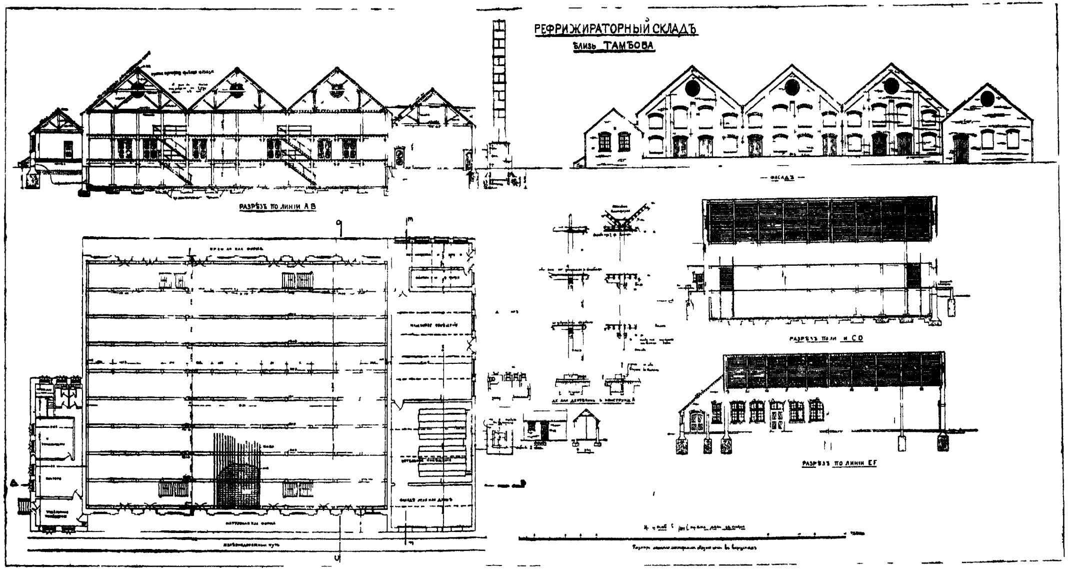
РЕФРИЖИРАТОРНЫЙ СКЛАДЪ
близъ ТАМБОВА
РАЗРѢЗЪ ПО ЛИНІИ АВ
ФАСАДЪ
РАЗРѢЗЪ ПО ЛИ И СD
РАЗРѢЗЪ ПО ЛИНІИ ЕF

FIG 123

ferro-concrete is a difficult material to which to attach heavy pipes and fittings. With steel-framed buildings these considerations do not apply, and within limits the owner can do pretty well what he likes. For this reason, unless the owner is quite definite that alterations will not be required, steel-framed buildings are to be preferred to those constructed of ferro-concrete. In a ferro-concrete building the designer is always torn between the proportion of steel reinforcement and the quantity of concrete, the less concrete the more reinforcement, and vice versa. This factor has a direct bearing on the size of the columns and the floor beams, and on the thickness of the floors. To avoid the excessive use of steel, where heavy loads are to be carried, the main beams are made very deep and are haunched where they join the columns. The secondary beams are also of considerable size. This is illustrated in Fig. 149 (p. 434), where the floors for a special reason were 30 ft. span, and were designed to carry a superimposed load of 560 lb. per sq. ft.

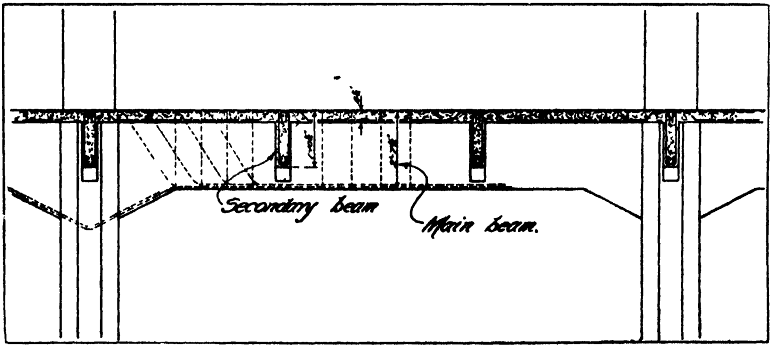

FIG. 124

A typical section through a concrete floor is shown in Fig. 124, which is the construction frequently put forward by inexperienced designers for use in cold storage buildings. It will be observed that the dimension from the top of the floor slab to the underside of the main beams is 2 ft. 7½ in., while from the same point to the underside of the secondary beams is 1 ft. 10½ in. This latter space is absolutely wasted, as the refrigerating pipes have to be kept below the level of the secondary beams. The depth of the main beams also interferes with economical stacking and air circulation. Within recent years United States ferro-concrete floors have been constructed consisting entirely of a floor slab supported on the columns only, the main and secondary beams being entirely

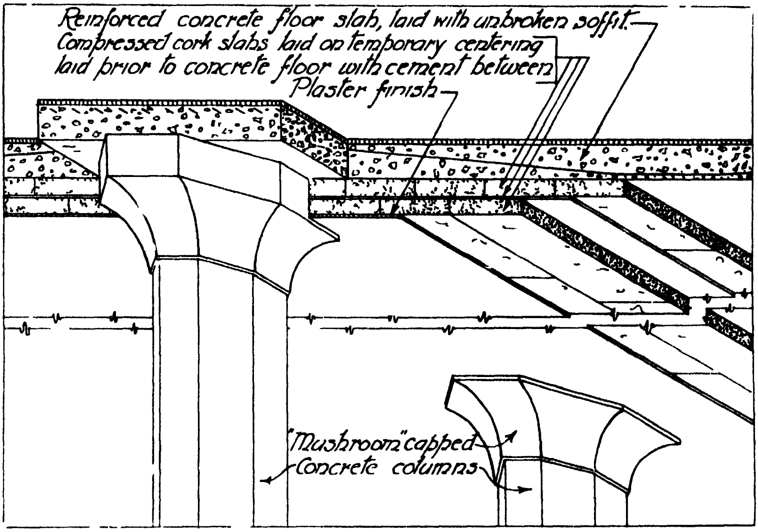
Reinforced concrete floor slab, laid with unbroken soffit.
Compressed cork slabs laid on temporary centering
laid prior to concrete floor with cement between
Plaster finish
"Mushroom" capped
Concrete columns

FIG 125

dispensed with. A warehouse recently erected to the designs of Mr. Louis Christian Mullgardt, F.A.I.A., of San Francisco, was constructed in this way. Mr. H. P. Henschien has also used the same design in cold storage and packing houses. It is illustrated typically in Fig 125, and is known as mushroom construction.

The advantages of the design for ordinary warehouse construction are very great, as there is no space lost between the floors except the actual thickness of the floors themselves. This considerably reduces the total height of a building of several floors, and of course goods can be packed solid from floor to ceiling if desired. In cold storage warehouses it also offers the same advantages with others in addition, viz., the unobstructed area of the underside of the floor permits the refrigerating pipes being put in any position that may be desired, and offers no obstruction to the circulation of the air.

When ferro-concrete is used the modern practice is to construct the outer walls merely as a containing shell. The floors are not supported from the walls, but are carried at the edges from columns placed a short distance inside the walls. This allows the insulation, generally of cork slabs, to be carried between them and the walls proper, and to form an unbroken sheet or envelope round the whole of the outer wall. It is, of course, necessary to tie the outer wall and inner columns together at intervals by means of suitable tie rods, but the area of these is so small that the leakage of heat inwards through them is of no appreciable consequence. Naturally, the building laws of the various countries have to be complied with in these designs.

Ferro-concrete, or concrete, floors and walls render the fixing of cork slab insulation particularly easy. With walls the slabs form the shuttering, the cement from the concrete runs into the unevenness of the surfaces of the cork, and when the concrete sets the slabs of cork adhere firmly to it. With floors or ceilings the cork slabs are laid on top of the shuttering, the concrete is laid on top of it and the same thing happens. The second layer of cork is secured to the first, being either set in cement mortar like tiles or bedded in hot liquid bitumen. The slabs are secured while setting by wooden skewers.

Steel Construction. A typical example of steel construction for cold storage buildings is shown in Fig. 126. The exterior stanchions are encased in brickwork, and the panels are built in brickwork in the usual way. It is important to use only good, hard vitrous bricks, so as to reduce the water soakage through them to the minimum. The wall stanchions are double with a space of 8 in. or so between them, and are connected together by steel plate distance pieces at each floor. These distance pieces and the tie rods between the wall and floor joist, which are shown in the illustration, form the only connection through the insulation, and the amount of heat conducted through them is not great. If the building laws

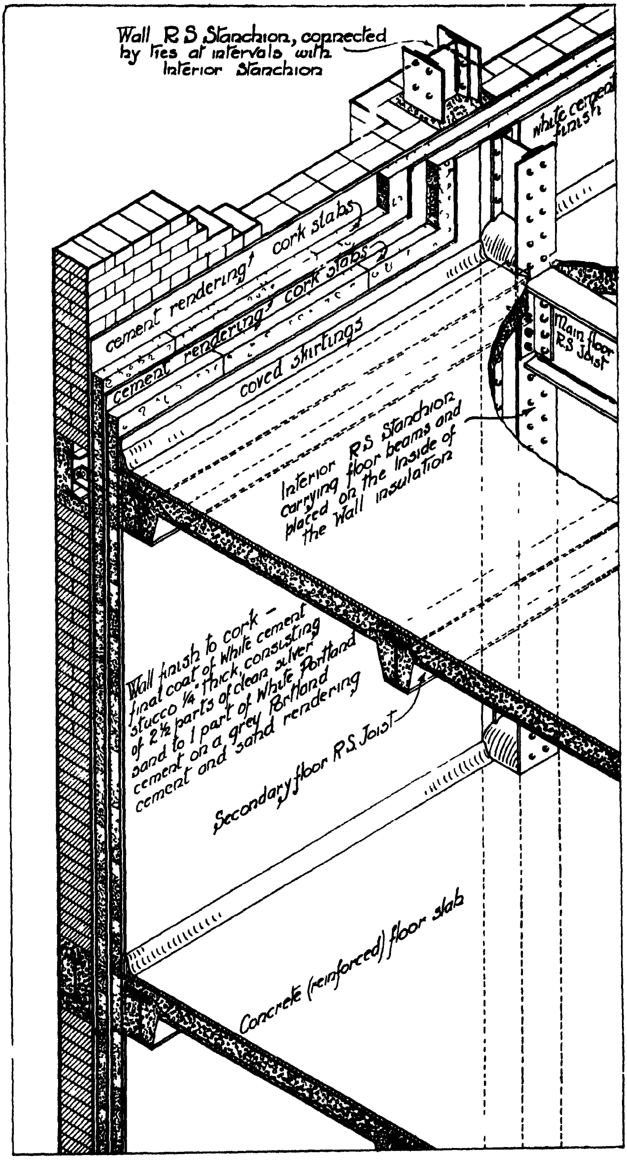
Wall R S Stanchion, connected by ties at intervals with Interior Stanchion
white cement finish
cement rendering, cork slabs
cement rendering, cork slabs
coved skirtings
Main floor R.S Joist
Interior R.S Stanchion carrying floor beams and placed on the inside of the wall insulation
Wall finish to cork - final coat of White cement stucco ¼" thick, consisting of 2½ parts of clean silver sand to 1 part of White Portland cement on a grey Portland cement and sand rendering
Secondary floor R.S. Joist
Concrete (reinforced) floor slab

FIG. 126

permit, oak distance pieces with a bolt or bolts passing through them, from stanchion to stanchion, can be substituted for the steel plates with benefit from the insulating point of view. The floors are kept clear of the wall insulation, which is fixed to the outside wall with cement mortar as described above. In consequence it forms a continuous sheath or envelope right round the building. The stanchions pass right through the floor to their foundations, and in order to avoid the conduction of heat through them from the earth beneath, they are insulated on the lowest floor only. The area of the stanchions is infinitely less than their equivalent in ferro-concrete, and the space saved is considerable.

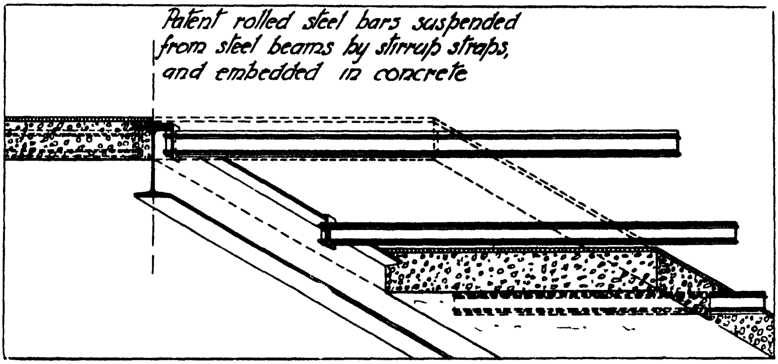
Patent rolled steel bars suspended
from steel beams by stirrup straps,
and embedded in concrete

FIG. 127

The floors can consist of the usual main and secondary beams as shown, or of flat surfaces between the main beams, the reinforcement being either ordinary steel or Colombia bars, as in Fig. 127. The depth of the main beams is small compared to ferro-concrete. They occupy about the same space as the refrigeration pipes, which nest between them and there is no loss of headroom, as shown in Fig. 124. This would not apply to a store cooled by air circulation, but in that case there is a good deal of space occupied by the air ducts. In a building in the London area and some other localities the stanchions and floor beams would have to be encased in concrete.

In considering the insulation of any cold store it is most important to pay particular attention to the foundations.

The ground is constantly at a higher temperature than is generally supposed, and while heat can leak in from it, if the insulation is faulty or insufficient, the ground can also become frozen. A case in the author's experience occurred in New Zealand. The ground under the refrigerated room became frozen, expanded, and nearly brought the whole range of buildings tumbling down. Considerable damage was done and a lot of expense had to be incurred before matters could be put right. The insulation of the lower floor is therefore particularly important.

Sprinklers. Automatic sprinklers are not commonly employed in cold storage buildings, but in London, if a building is protected by sprinklers, it is permitted to do things under the Building Act which would not be allowed if they were absent.

Any sprinklers fitted must of necessity be on the dry system on account of the low temperature. In this system the sprinkler pipes in the stores are full of air, water is only admitted to the pipes when the air is released by a sprinkler head " blowing " from a fire or other cause. Fires in cold stores are not common, and as the sprinkler pipes are rather a nuisance for several reasons, it is unusual to fit them except for some special purpose. In ordinary warehouses they are, of course, of the utmost value.

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LLOYD'S REGISTER OF SHIPPING

RULES FOR THE SURVEY OF REFRIGERATING MACHINERY AND APPLIANCES OF FROZEN MEAT STORES

Section 1. 1. On the application of the proprietors of frozen meat stores, he committee will authorize their surveyors to survey the refrigerating machinery and appliances, and in those cases where the following conditions are complied with and a satisfactory report is received from the surveyor, certificates of these surveys will be issued and the notation of Lloyd's RMC (*in red*) (i.e. Lloyd's Refrigerating Machinery Certificate) will be made in the Special List of Frozen Meat Stores in the Society's Register Book. In cases in which the refrigerating machinery and appliances are constructed under the special survey of the Society's surveyors, and to their entire satisfaction, the notation ✠ Lloyd's RMC (*in red*) will be assigned. The number of refrigerating units, number of compressors, the system of refrigeration, the name of the maker of the machines, the method employed for cooling the chambers and the nature of the insulation, the refrigeration or ice melting capacity in tons per 24 hours, and the number and total capacity of the insulated frozen meat chambers in cubic feet, will be recorded in the Special List in the Register Book.

> NOTE. A refrigerating unit comprises a prime mover, one or more compressors, one condenser and one evaporator or cooler, where these are employed.
>
> If the prime mover is a steam engine and each cylinder drives a corresponding compressor, or if there is more than one motor similarly arranged and each compressor is connected to its own condenser and evaporator or cooler (not necessarily in separate casings) these machines are to be described as two or more units, as the case may be, provided each unit can be used either in combination or separately.
>
> If a machine has more than one compressor, but is driven by a single prime mover and has only one condenser and one evaporator or cooler, it is to be described as one unit with one or more compressors.
>
> In the case of compound compressors the high and low pressure cylinder are to be considered as a single compressor.
>
> NOTE. The refrigeration or ice-melting capacity of the machines in tons per 24 hours should be calculated at the rate of 318,080 B.T.U. per English ton (i.e. 2,240 lb.) with temperature of evaporation = 5° F. (– 15° C.), and temperature of liquid refrigerant in the condenser = 86° F. (30° C.).

2. *Submission of Plans.* In cases where the refrigerating machinery and appliances are to be constructed under special survey, plans or specifications are to be submitted for consideration.

Section 2. 1. *Power of Machinery.* (*a*) The refrigerating machinery is to be of approved construction and of sufficient power to maintain a temperature of 15° F. simultaneously in all the insulated chambers when running 18 hours per day under the following conditions, viz.—

> (*b*) Not less than two compressor units are to be fitted and each of these units is to be capable of maintaining all the insulated chambers at the temperature prescribed in *paragraph* (*a*).
>
> (*c*) Where three compressor units are fitted, and their working parts are interchangeable, any two of the three units are to be capable of maintaining all the insulated chambers at the temperature prescribed in *paragraph* (*a*).
>
> (*d*) Where four compressor units are fitted, and their working parts are interchangeable, any three of the four units are to be capable of maintaining all the insulated chambers at the temperature prescribed in *paragraph* (*a*).
>
> NOTE. (*a*) A compressor unit comprises a compressor and condenser, and an evaporator or cooler where these are employed.
>
> (*b*) Where the direct expansion system of refrigeration is employed the number of sections and the cooling surface of the pipes in the chambers are to comply with the requirements of *Section* 3, *clause* 6.

(c) In all cases the working and spare compressor units are to be coupled up to the main system, ready for immediate use.

2. *Motive Power.* Each compressor is to be driven by independent means, or, alternatively, the motive power is to be in duplicate.

Where the compressors are electrically driven, a spare electric generator is to be fitted, unless the power is supplied by a public generating station.

Where electric transformers are installed on the premises, a spare transformer is to be fitted.

3. *Hydraulic and Other Tests.* In the case of new refrigerating machinery and appliances, the tests recommended for the various parts are as follows, viz.—

(*a*) CO_2 compressors, separators, condenser and evaporator coils, headers and connections to be tested by hydraulic pressure to 3,000 lb. per sq. in., and afterwards by air pressure to 1,500 lb. per sq. in., whilst submerged in water.

(*b*) NH_3 compressors and cast iron or steel connections to be tested by hydraulic pressure to 600 lb. per sq. in. Where compound compressors are fitted, the low pressure compressor and cast iron or steel connections to be tested by hydraulic pressure to 200 lb. per sq. in.

(*c*) NH_3 condenser, evaporator and air cooler coils to be tested by hydraulic pressure to 1,500 lb. per sq. in., and afterwards by air pressure to 500 lb. per sq. in., preferably whilst submerged in water.

(*d*) NH_3 plant, after erection in place, to be tested by air pressure; the gas delivery side (i.e. from the compressor to the liquid expansion valves) to 200 lb., and the return side, including the direct expansion piping for the chambers (i.e. from the liquid expansion valves to the compressor suction valves) to 150 lb. per sq. in.

(*e*) Brine piping, after erection in place, to be tested by air or water pressure to 90 lb. per sq. in.

(*f*) Gas evaporator casings of cast iron and gas condenser casings, whether of cast iron or steel, where of enclosed type, to be tested by hydraulic pressure to 15 lb. per sq. in., or to double the working pressure, whichever is the greater.

(*g*) Gas evaporator wrought iron and steel casings, where of enclosed type, to be tested by hydraulic pressure to 30 lb., if gravitation type, or to 50 lb. per sq. in. if pressure type, or to double the working pressure, whichever is the greater.

NOTE. In the case of partial renewals, air tests which would involve the application of such tests to any part of the existing system should not be applied.

4. *Cooling Tests.* (*a*) Upon completion of the installation under special survey, the refrigerating machinery is to be tested under working conditions, and the insulated chambers are to be cooled down simultaneously to about 15° F.

(*b*) The whole of the refrigerating power may be used in order to reduce the temperature, but the specified temperature is to be maintained in the insulated chambers for a period of 12 hours with the spare compressor unit, prescribed in *Section* 2, out of action.

(*c*) The temperatures of the chambers are to be noted at intervals and the results of the tests are to be reported.

Section 3. 1. *Insulation.* (*a*) The insulation is to be of approved material and of suitable thickness, according to the position of the chambers and the nature of the material used. The insulating material is to be of good quality, and where charcoal, silicate cotton, granulated cork or similar media are employed, these are to be properly packed. The wood work is to be sound and in good order and of efficient construction.

(*b*) The details of construction, showing the amount and nature of the insulating material employed are to be reported.

2. *Openings in Chambers.* The doors of the insulated chambers are to be efficiently insulated and are to be arranged to be opened or closed from either side. The openings are to be so arranged that the low temperature in the chambers may be maintained within reasonable limits during receipt or delivery of goods.

3. *Battens.* Permanent battens are to be fastened on the walls, and portable battens are to be provided for the floor, of all insulated chambers.

4. *Thermometers.* Thermometers, or other approved apparatus, are to be provided in the insulated chambers. A certified standard thermometer is also to be kept on the premises in order that the accuracy of the thermometers, or the temperature recording apparatus in the chambers, may be checked occasionally.

5. *Brine Cooling System.* (*a*) Where the brine system of refrigeration is employed the cooling pipes in each refrigerated chamber of over 5,000 cu. ft. capacity are to be arranged in not less than two sections, and the cooling surface is to be sufficient to maintain the working temperature of the chamber when one of the sections is out of use. Isolating valves or cocks are to be fitted to each section of cooling pipes.

(*b*) The brine circulating pipes and brine tanks should not be galvanized on the inside.

(*c*) In cases where internally galvanized tanks or cooling pipes are fitted, the brine cooling and return tanks, if of closed type, are each to be provided with a ventilating pipe or pipes led to the open air in a situation where no danger will be incurred from the issuing gas, and each ventilating pipe is to be fitted with a wire gauze diaphragm which can be easily removed for renewal.

(*d*) Where the tanks are not closed the compartments in which they are situated are to be efficiently ventilated.

6. *Direct Expansion System.* Where the direct expansion system of refrigeration is employed, the cooling pipes in each refrigerated chamber of over 5,000 cu. ft. capacity are to be arranged in not less than two sections, and the cooling surface is to be sufficient to maintain the working temperature of the chamber when one of the sections is out of use. An expansion valve and a return gas valve or cock are to be fitted to each section of cooling pipes.

7. *Gas Condensers, Air Cooling Batteries, and Brine Coolers.* (*a*) The number and capacity of the sections of coils or elements of the gas condensers, air cooling batteries and brine coolers are to be in accordance with those of the compressor units prescribed in *Section 2.*

(*b*) A shut-off cock or valve is to be provided at the inlet and outlet of each section of coils or elements.

8. *Fire Extinguishing Appliances.* Ample fire extinguishing appliances are to be provided.

9. *Conveyance of Goods.* It is recommended that all goods should be conveyed to the store in efficiently insulated road vans, railway vans or lighters, and that the goods should be unloaded, as far as practicable, under cover.

10. *Gas Masks.* It is recommended that gas masks should be provided where an ammonia system is installed.

Section 4. *Spare Gear.* 1. *Compressor Units.* Where the working parts of the compressor units are not interchangeable, a sufficient amount of spare gear is to be supplied.

2. *Air Circulating Fans.* Where electrically driven, a spare armature for each pattern of motor used is to be supplied. Where more than one air

cooling battery is fitted, and they are not cross connected, a spare shaft and bearing bushes for each pattern of air circulating fan used are to be supplied.

3. *Cooling Water and Brine Circulating Pumps.* Where electrically driven, a spare armature for each pattern of motor used is to be supplied.

4. *Brine Cooling System.* Where the brine system of refrigeration is employed for cooling the chambers, a spare brine pump is to be fitted and connected ready for use.

5. *Cooling Water Supply.* The cooling water for gas condensing purposes is to be obtained from more than one source. Where the cooling arrangements are solely dependent on pumping, a spare water circulating pump is to be fitted and connected ready for use.

Section 5. *Periodical Surveys.* A periodical survey is to be held every three years as follows—

1. *Motive Power.* (*a*) Where steam engines are fitted, the boilers and their mountings are to be examined as far as practicable. The Boiler Insurance Co.'s certificate is to be exhibited, and the date of same is to be noted. The working parts of the steam engines are to be opened out and examined.

(*b*) Where gas engines are fitted, the producers are to be examined as far as practicable. The working parts of the gas engines are to be opened out and examined.

(*c*) Where internal combustion engines are fitted, the working parts of the engines are to be opened out and examined.

(*d*) Where electric generators and motors are fitted, their shafts, shaft bearings, commutators, and brush fittings, are to be examined.

(*e*) Where reduction gears are fitted, the shafts, shaft bearings, and teeth of the gears, are to be examined.

2. *Compressors.* The working parts of the compressors are to be opened out and examined. In dry air machines special attention is to be given to the condition of the air compressor and expansion cylinders, their pistons and valves. In other machines special attention is to be given to the condition of the compressors, including the pistons, piston rods, glands, and valves.

3. *Refrigerating Condensers and Evaporators.* The refrigerating condenser coils or pipes and the evaporator coils, or direct expansion battery piping, are to be examined as far as practicable.

The refrigerating liquid pipes, separators and receivers, and the gas return pipes, are to be examined externally as far as practicable.

Where the condenser and evaporator coils are enclosed in tanks, the latter are to be examined internally as far as practicable, and, if necessary, they are to be cleared of any existing deposit from the cooling water or brine.

Where surface condensers are employed, the cooling water pipes are to be examined externally, and, if necessary, they are to be cleared of any existing obstruction.

4. *Insulation.* The cold chambers are to be examined with regard to cleanliness.

The insulation, wall and floor battens, pipe guards, and door fittings of the cold chambers, are to be examined.

Where charcoal, silicate cotton, granulated cork, or similar media are employed for insulating purposes, the insulation is to be carefully examined for fullness by sounding with a hammer, and, if necessary, by boring. The test holes afterwards are to be efficiently closed.

5. *Brine Pipes.* Where brine pipes are fitted, these are to be examined whilst in a frosted condition, and under brine pressure.

6. *Direct Expansion Pipes.* Where direct expansion pipes are fitted, these are to be examined whilst under full working conditions.

7. *Tests.* The refrigerating machinery is to be tested under working conditions. The required temperatures of the insulated chambers are to be maintained with one-half, or, in the case of three units, two-thirds, or, in the case of four units, three-fourths of the refrigerating units at work.

8. *Thermometers.* The thermometers in use are to be checked by means of a standard thermometer.

9. *Fire Extinguishing Appliances.* The fire extinguishing appliances are to be examined.

10. *Alterations to Existing Stores.* All extensive alterations of refrigerating machinery, or insulation, or additions to the capacity of stores which hold the Society's certificate, are to be carried out under the supervision of the Society's surveyors, and particulars should be submitted for consideration before the work is commenced.

Exhibition Chambers. When produce has to be exhibited and, at the same time, refrigerated, a special form of cold storage chamber is required. In these cases, it is necessary to observe three governing factors. First, the cooling must be even, lasting, and efficient, even after the machine has been shut down ; secondly, the goods behind the plate glass must appear to the observer in their natural colours, and thirdly, there must be no condensation on the glass, which must remain at all times clean and bright.

It is not an easy thing to meet these requirements, and no matter how much care is taken, the last is a constant source of anxiety and difficulty, as the temperature and density of the air between each layer of glass is different, and it is very hard to prevent leakages from the one to the other.

Fig. 128 illustrates one of six large cabinets which were designed by the author for the New Zealand Government and were installed in their pavilion at the Wembley Exhibition, 1924–1925. The photograph was taken in a darkened hall, and shows the effect of the internal lighting. The cooling in these cabinets was effected on the loft principle by brine drums placed above a false ceiling. These drums were of considerable size and contained a large reserve of cold which ensured an even temperature, and the false ceiling gave a natural circulation to the air in the chamber.

The internal lighting was specially arranged to overcome the mirror effect of the plate glass and also to counteract the greenish tinge which seems inseparable from post-war plate glass, at any rate, in England. Condensation was prevented, by regulating the temperature drop between the outside and the inside in a sufficient number of stages, and by keeping the air in each stage dry by the usual method of employing calcium chloride as a dehydrating medium.

The cabinets were 28 feet long by 20 feet wide, and had glass on all four sides, thus giving an uninterrupted view of their contents to the public perambulating around them.

The late King and Queen Mary were much interested in these cabinets, and on a hot July day Her Majesty could not believe that there were 14 degrees of frost behind the glass, until the door was opened and she felt the cold air rushing out.

Small Cold Stores. A large cold store is only a profitable property on regular trade routes or in populous centres, but food will go bad irrespective of locality. A great deal of attention, therefore, has been given to the design of small refrigerating installations suitable for small hotels, restaurants, provision merchants, butcher shops, yachts, hospitals, asylums, and private houses.

In most of these cases skilled attention is absent, and unless the plant is designed to look after itself, with only occasional visits from a skilled man, it is of little use. The aim, therefore, has been to make them foolproof so that as long as the machine contains a charge of refrigerant, and is in good mechanical order, it only has to be started and stopped.

The small refrigerating plant is also a very useful adjunct to large private country houses in providing proper facilities and temperatures for the storage of provisions, ice for table use, and on large sporting estates it is often arranged to freeze a room or rooms for the preservation of game.

A small cold store may be cooled either by ice or by means of a refrigerating machine. For quite small stores, which are generally referred to as safes or boxes, ice has some advantages when a regular supply is obtainable at a reasonable price. The first cost involved is very much less, which is frequently a great consideration to the small trader. It effects its refrigeration for twenty-four hours a day, and requires no

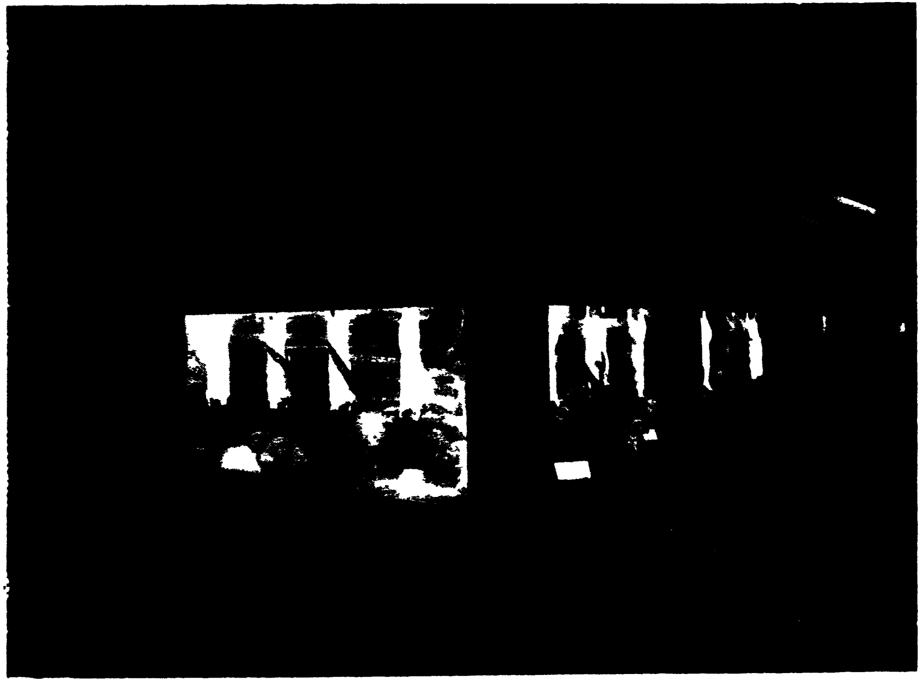

FIG. 128. EXHIBITION CHAMBER

attention beyond regular replenishment. There is nothing mechanical to go wrong. On the other hand, the handling of ice is a somewhat laborious and messy business. It effects its refrigeration by melting, so that there is always a good deal of water present which is difficult to keep out of the insulation.

FIG 129

A temperature of between 40 and 45° F. is about as low as can normally be obtained. This is some 6 to 10° F. higher than the normal user actually requires, and the moist temperature which results from the presence of the melting ice and water is not favourable for storage. A lower temperature can be obtained by the use of ice and salt, but this adds considerably to the cost of working.

There is now a great choice of small machines designed for the small user where the attention required is reduced to a minimum, and the labour is probably very little, if any, more than that which would be involved in handling ice.

For small cold stores, the refrigerating plant is generally a miniature one of the compression type, and as the machine has often to be fixed in some restricted place on a shop premises, which often adjoins living quarters, a CO_2 machine frequently has an advantage due to the harmless and odourless nature of the gas used.

In small cold storage rooms it is advisable to arrange for as large a volume of brine as possible in the cooling appliances to act as a cold accumulator. This is generally obtained by placing the evaporator coil piping in a flat, closed, steel tank, which is filled with brine and erected near one of the side walls, such a tank being generally termed a brine wall. The tank should be placed as high up as possible, and it should have a diaphragm in front, as shown in Fig. 129, both to prevent actual contact of goods with the tank, and to induce a circulation of air over it and through the room. In some cases, where there is ample height available but restricted floor space, the tank can most conveniently be arranged in a compartment over the cold room proper with intercommunicating ducts through which the air can circulate, the construction then being similar to the pipe lofts, described elsewhere.

In addition to the tank surface it is a good practice to arrange for a certain amount of the evaporator coil piping to be directly exposed to the air to assist in rapid cooling, and a small fan motor driven to give a gentle positive air circulation is always desirable.

The fan motor should preferably be outside the insulation and the fan inside, carried on an extended spindle. If the fan motor is inside it is liable to be damaged by moisture deposited from the air. In any case, means should be provided for renewing the air in the room at frequent intervals. When the doors open into a room in which the air is fresh the ordinary opening and closing is sufficient, but if the store is in a confined space or open only on the top, fresh air should be introduced by the fan.

For all small machines, when current is available, the electric motor is now almost universally used as a source of power on account of its convenience, cleanliness, relative silence, the small space occupied, and the small amount of attention required, but in country districts where current is not available a small oil engine can be used.

Fig. 130* illustrates a small self-contained plant, consisting of a cold room cooled by a small belt-driven ammonia compression machine. The lettering on the illustration together with the key make the names and functions of the various parts quite clear.

Hospitals require refrigerating plant not only to preserve provisions, milk, etc., but also in the manufacture of ice for medicinal purposes, where the purity of the supply must be beyond all question, in the cooling of the mortuary, and in the preparation of cultures.

In many hotels, apart from its ordinary duties of preserving provisions, the refrigerating machine is also used for water coolers, for the iced water supplies at various points, for making ice-cream, and occasionally in hot climates for air cooling and conditioning for the reception rooms. The two latter duties, when required, each call for special machines for that particular purpose—ice-cream making because the temperature required is so much lower, and air conditioning because the temperature is so much higher than the conditions required for the ordinary refrigerating service.

While in smaller hotels the duties of the refrigerating machine are often confined to the cooling of one or two small rooms, in large hotels there are frequently, in addition, a number of relatively small cabinets, as shown in Fig. 131, to be cooled, which are widely scattered over the building. The supply of refrigeration to these involves long pipe leads and other complications. These small rooms, as will be seen from the diagram on p. 149, require, in any circumstances, a large

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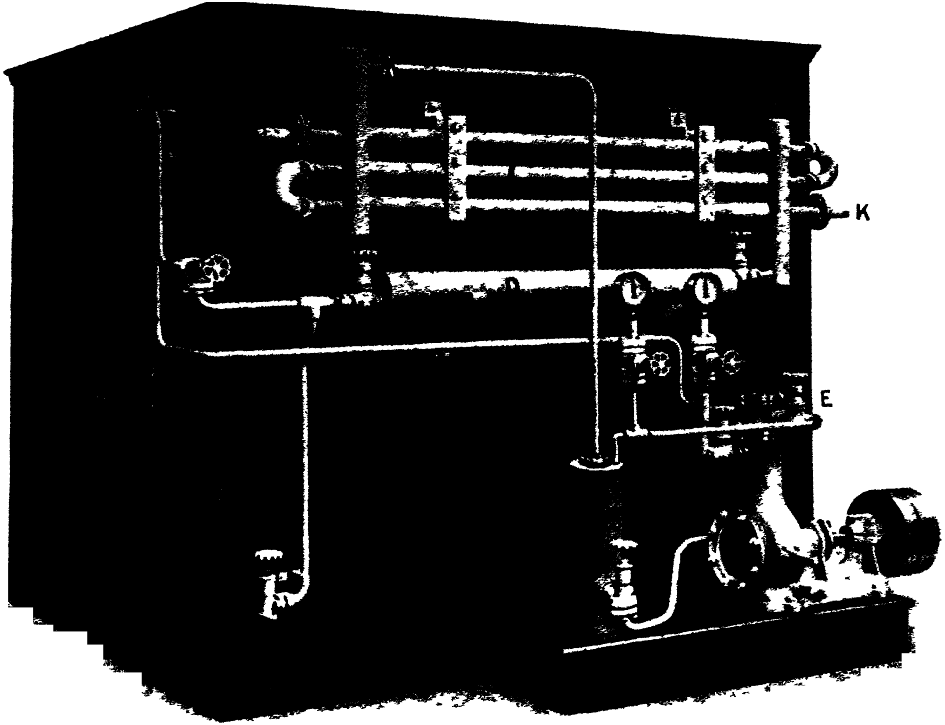
* Messrs. L. Sterne & Co., Ltd., Glasgow.



A = ammonia compressor.

B = oil separator.

C = double pipe ammonia condenser.

D — ammonia storage tank.

E = ,, discharge valve

F — , main liquid valve

G = ,, expansion valve.

H — ,, return valve.

J = ,, charging valve

K = water inlet

L = ,, outlet

FIG. 130

refrigerating power relative to their total capacity. Consequently for hotel use the refrigerating power, as found from this diagram, should be increased by from 50 to possibly 100 per cent. Experience shows that the doors are seldom closed, and that the conditions generally are probably the hardest that a refrigerating machine has to meet.

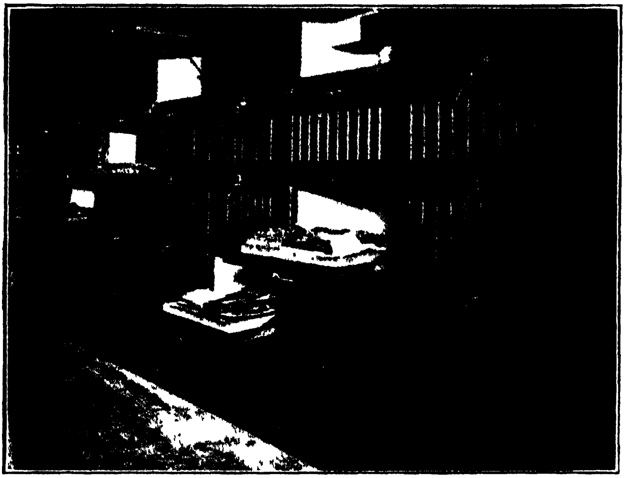


Fig. 131

For the still smaller users, who only require a small room or cabinet, and for domestic users of refrigeration, there is now—as the advertisement columns of the technical journals show—a considerable choice of machines.

The majority of them are miniature compression plants using a low pressure refrigerant, generally sulphur dioxide or methyl chloride. Air-cooled condensers are almost universal for the smaller units.

These machines are started and stopped automatically at predetermined temperature limits by means of a thermostat in the cooled space, and when water is used for cooling the condenser its supply is automatically controlled.

The Frigidaire machine* is illustrated in Fig. 132.

Fig. 133 illustrates a compact machine put on the market by

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* Frigidaire, Ltd., The Hyde, London, N.W.9.

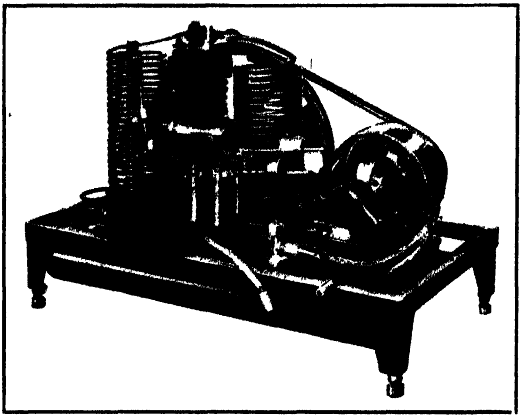

FIG 132

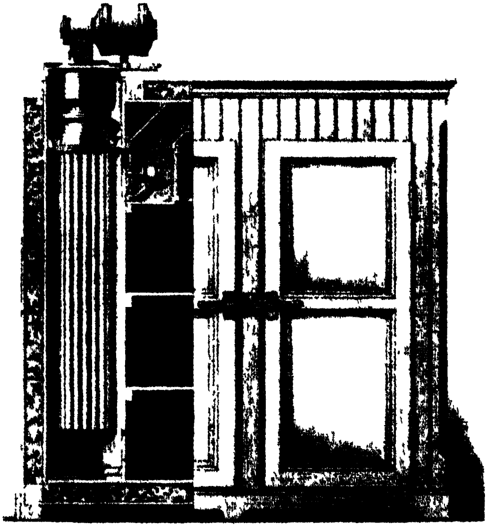

FIG. 133

Messrs. Sulzer.* The refrigerating medium used is methyl chloride and the plant is entirely self-contained. It is automatic in action and consists of a rotary compressor direct coupled to an electric motor, which can of course be supplied suitable for any voltage, a counter current condenser, automatic expansion valve, and the evaporator. If a fan is required for air circulation, as shown in the illustration, it can be driven off a pulley on the extended shaft of the motor. The absence of any reciprocating parts ensures silent running and absence of vibration. The only connections required are those for electricity and water, and attendance is confined to switching on the one and turning on the other. The plants are made in various capacities, ranging from 5 cwt. to 4½ tons refrigeration, and the power consumed varies in proportion from ½ to 6 b.h.p.

The absorption principle has always appeared attractive as a solution of the need for very small refrigerating machine units, as by intermittent working and using one vessel to serve alternatively as an absorber and as a generator, it has been possible to arrange for the complete absence of any glands or other ordinary places from which leakages might occur. In the past, many endeavours have been made to perfect small intermittent working absorption machines, but owing to the alternations of heat and cold, allied, possibly, with indifferent workmanship, these have generally given so much trouble, that the type has failed to make good. There is now available, however, a very small absorption machine in the Electrolux refrigerators† made under Platen-Munters patents. This is a continuous acting machine in which there are no pumps or working parts. There is one total pressure throughout, so that circulation of the strong and of the weak aqua ammonia can be obtained by means of heat in much the same way as circulation of water in any central heating system.

This remarkable result is obtained by using a proportion of an inert gas, for instance hydrogen which, in working, accumulates in the evaporator and absorber so that although the total pressure is the same throughout the three vessels, i.e. generator, evaporator, and absorber which form the system, the partial pressure of the ammonia in the evaporator is low, and the entering liquid evaporates at a corresponding low pressure and temperature, the working cycle being illustrated in Fig. 134.

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* Messrs. Sulzer Bros., Winterthur (Switzerland) and London

† Electrolux Ltd., 155 Regent St., London, W.1.

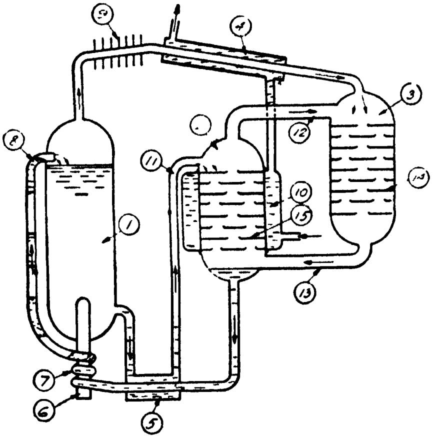

Fig. 134.—Diagram Showing Principle of Electrolux Cooling Unit

1. Generator.
2. Absorber.
3. Evaporator.
4. Condenser.
5. Temperature exchanger.
6. Heating medium.
7. Thermo syphon.
8. Strong liquid inlet.
9. Rectifier.
10. Cooling jacket.
11. Weak liquid inlet.
12. Hydrogen in.et.
13. Mixed gas outlet.
14. Discs in evaporator.
15. Discs in absorber.

The machine works continuously and without trouble in temperate climates, but the makers should be consulted before installing it in tropical regions.

The Autofrigor,* is a self-contained unit made entirely enclosed so that there is no gland or other possible source of leakage. At the same time it has a motor-driven compressor. This feature is obtained by constructing the machine as shown in the section (Fig. 135), with the casing between the stator and rotor of the motor. These motors can be made for all alternating currents, but when there is a direct current supply, it is necessary to use a special transformer.

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* Messrs. Escher Wyss & Co., Zurich and London.

Ship Work

The application of mechanical refrigeration to ship work really requires a whole book to itself. The history of its development and the way in which new problems, both in design and application, have been successfully overcome is a veritable romance. It is to be hoped that while the men who met and surmounted these difficulties are still with us, some pen, more gifted than the author's, will take up the task and tell the tale. The successful application of refrigerating machinery on board ship may be taken as the starting point of the cold storage industry, which is so largely employed in the storage of meat and provisions from overseas.

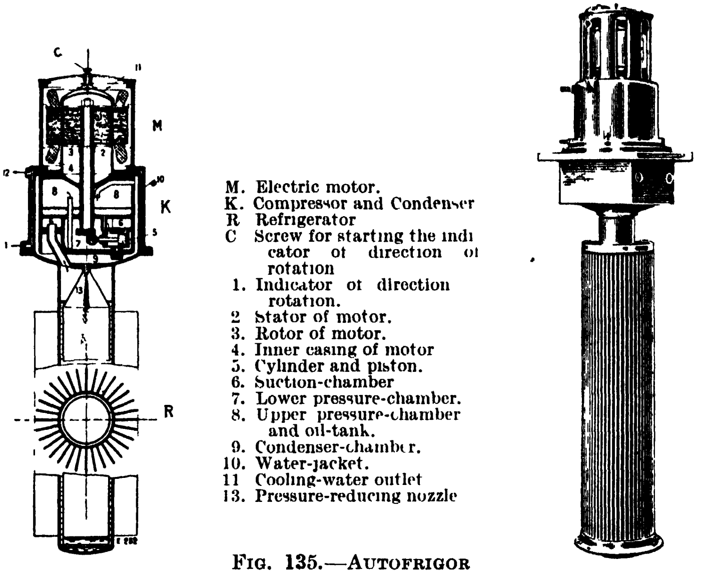
C
11
M
12
10
K
5
1
13
R
M. Electric motor.
K. Compressor and Condenser
R Refrigerator
C Screw for starting the indicator of direction of rotation
1. Indicator of direction rotation.
2 Stator of motor.
3. Rotor of motor.
4. Inner casing of motor
5. Cylinder and piston.
6. Suction-chamber
7. Lower pressure-chamber.
8. Upper pressure-chamber and oil-tank.
9. Condenser-chamber.
10. Water-jacket.
11 Cooling-water outlet
13. Pressure-reducing nozzle

FIG. 135.—AUTOFRIGOR

As has been noted in Chapter III, the early cold air machines installed on board many sailing ships had to serve as the freezing works in Australia—to maintain a frozen temperature in the holds on the voyage over, and finally to act as a cold store pending delivery of the cargo.

Apart from the special and particular duty of refrigerating insulated holds for the carriage of perishable provisions as cargo, refrigerating machinery is now almost universally installed on all vessels, from the largest Atlantic liners down to small yachts. Its duty consists in cooling rooms for the storage of provisions for passengers and crew, in making small quantities of ice for table use, and in providing a service of cold drinking water.

The vessels equipped for the frozen and chilled meat trades are by far the most important, both in number and capacity. There are many frozen meat carriers having an insulated capacity of about 600,000 cu. ft. or capable of carrying, say, 180,000 carcases of mutton. In the carriage of chilled meat on board ship, refrigeration has reached its highest large scale commercial development in the maintenance of steady temperatures, which are kept at 29·5° F. with a variation of less than half a degree throughout the voyage.

In the application of refrigeration on board ship the CO_2 refrigerating machine occupies a predominant position. Owing to the harmless nature of the gas—in the quantities used—the Board of Trade regulations permit the machine to be placed in the engine room or in any other convenient or confined space, whereas an ammonia machine has to be fixed in a special deckhouse. This is a particular advantage when the refrigerating machine is only required for cooling provision rooms, as it can be placed directly under the supervision of the ordinary watch-keeping engineers. In boats equipped for large refrigerated cargoes special refrigerating engineers are carried, so that from the point of view of supervision the advantage of CO_2 is not so great.

With a CO_2 machine the condenser can be constructed of copper piping and is practically immune to the corrosive action of sea water. With ammonia the piping must be of iron or steel, which is rapidly affected and can be only partially protected by galvanizing.

A further factor in the popularity of CO_2 machines has been the enterprise allied with a sound conservatism that has characterized all marine work, together with the robust construction and good workmanship of those firms, notably

Messrs. J. E. Hall, of Dartford, who have developed the machine and specialized in its application on board ship.

The machines used are generally steam driven, and in the larger sizes having their own steam condensers, air and circulating pumps. With the development of the motor driven ship the electrically driven refrigerating machine is coming into greater use. In some recent designs the machines have been driven direct by Diesel engines.

The condensers are of the submerged type, and the evaporators are constructed as brine coolers, and are generally of similar construction to the condensers.

The brine is pumped through grids or coils of pipe placed both on the sides and ceilings of the holds. The grids are divided up into a number of sections, each having separate flow and return pipes controlled by valves at the machine or, in the larger units, in the evaporator and brine control space.

The brine system is sometimes made entirely enclosed with only a small vent pipe, to allow any air or gases which may accumulate to escape, but generally the returns discharge into an open tank. The quantity flowing through each section is regulated by a valve on the open discharge, and the brine pumps draw from the tank and deliver through the evaporator into the delivery header or headers.

The conditions for the cold storage of cargo on board ship are favourable, as there is no in and out traffic during the voyage. This advantage is to some extent counterbalanced by the steel construction of the hull, the hot engine and boiler rooms, and the sea water in contact with the skin plating which the insulation adjoins. The refrigerating power to cool the insulated spaces may be taken as approximately that shown in the diagram on page 149.

It is usual to allow a rather larger margin for provision rooms which are largely comparable to those in a hotel service. In large passenger liners long pipe leads to scattered small service cupboards and water coolers largely increase the refrigerating capacity required. In allocating the power of the refrigerating unit it is necessary also to keep in view the voyages to be run and to calculate the power on the worst conditions and highest temperature of condensing water likely to be encountered. The pipe surface in the insulated spaces is generously proportioned, particularly so in spaces for chilled meat, the quantity in these being at least twice the amount usually put in cold stores of similar capacity on shore.

In vessels carrying both chilled and frozen meat, separate brine services are maintained. The brine for chilled meat does not pass directly through the evaporator, but is maintained at the proper temperature by diverting into it some of the colder brine returning from the piping in the frozen meat holds. In the closed brine system this is effected by three way cocks, and in the open return system by troughs under the returns. This arrangement permits some of the cold brine to flow into a separate compartment or mixing tank, from which the warmer brine delivered through the piping in the chilled meat spaces is drawn.

An important trade in which a special fleet of vessels is employed is that of the carriage of bananas. The fruit is picked before it is ripe, and the refrigeration is provided to retard the process of ripening, so that it is landed at its port of destination in such a condition that it should be ripe after the normally short interval for distribution after landing. On loading up, the cargo is gradually cooled down to about 50° F. The system of cooling is by means of air circulation by powerful fans. The best method of stowing the fruit has been carefully studied, and it is stacked so that the air, in passing from the delivery direct to the return duct, has to pass through it in much the same way, in fact, as it passes through the boxes of apples in Fig. 137. When necessary fresh air is introduced, blown over the cooler, and cooled before it enters the fruit room. The coolers are of the dry pipe type, and with this relatively high temperature there is, of course, no difficulty with accumulations of ice or snow on the pipe surfaces. The refrigerating machinery has to be of considerable power in relation to the capacity of the fruit holds, as the whole of the contents have, in the first instance, to be cooled down.

In other vessels used for the carriage of fruit the refrigerating equipment is not exclusively arranged and applied for that purpose, but use is made of the ordinary insulated holds which may at other times be employed for the carriage of frozen meat, butter, or other produce, and these holds may or may not be provided with forced air circulation. Some air circulation at any rate is advisable, as pointed out in discussing the storage of fruit, and it is necessary to change the air at intervals. In cold storage the process of ripening is only retarded, and whilst it proceeds very slowly, it is not stopped. Fruit of any kind is a living organism, and in the process of ripening CO_2 is generated. A proportion of CO_2 is beneficial in retarding the ripening in storage rooms for fruit, but fruit needs some oxygen, and if the oxygen is too much reduced, as it may be in holds where the air is not changed throughout a voyage, the result, under certain circumstances, may be the suffocation of the fruit and the development of the disease known, in apples, as brown heart.

As the cargo spaces are completely emptied at the end of each voyage, there is no difficulty in removing the snow from the piping by thawing off. It is usual to provide a special hot brine service with a tank and pump. When hot brine is delivered through the grids the snow falls off with very little meltage, and it can be swept up and removed.

In addition to preservation of food, refrigerating machinery is used on warships to cool the magazine spaces and prevent deterioration of the propellents.

Cold Storage Management

The problems which day by day confront the manager of a modern cold store are many, and each has a direct bearing on the success of the undertaking under his control. Efficiency of the plant and machinery, labour problems, the economic use of storage space, securing of business, arranging for the receipt and delivery of different perishable commodities, cleanliness of premises, finance, etc., all play their part, and each requires close and constant thought if a reasonable return for the capital invested is to be secured.

Plant. The greatest factor of a successful business is that of efficiency in all departments, and in cold storage this applies more particularly to the machinery and buildings, including insulation, for everything depends primarily, not only on being able to maintain the required temperatures, but also in doing this economically. The care and maintenance of machinery must, therefore, have close attention ; it is not enough to be satisfied with seeing that the temperatures are correct, it is more important to know how the result has been accomplished. If the manager has technical and practical experience in refrigerating engineering, so much the better, but lacking this, one of his first thoughts will be the securing of reliable engineers to run his plant.

Fuel, whether coal, gas or electricity, is one of the principal costs ; where either of the two last are taken from a public supply service, a check on consumption is easily kept, but in a steam driven plant every effort should be made towards attaining good boiler efficiency. Coal should be bought on calorific values, and before arranging a contract for supplies it is advisable to test, under working conditions, sample truck loads of different classes of coal, to determine which is the best suited for the particular plant, considering price and quality. Having decided this point, the manager has to arrange for constant supplies, and decide the safe limit of stock on hand to meet contingencies of labour troubles, etc., because the very nature of his business demands constant service. The regular maintenance of machinery, a supply of the refrigerant used, oil, packing, etc., have all to be considered, and a sound insurance against stoppages will be the knowledge that a duplicate plant is ready, in every respect, for instant duty, should necessity arise. He must arrange for a thorough overhaul of all the machinery every year, and continuous operation or costly stoppages depend upon the thoroughness with which this is done.

Every part of the plant must be opened out and examined, and no part must be overlooked simply because it has been giving no trouble. If the latter is taken as an excuse for not bothering, then trouble is almost sure to develop in unexpected places, and usually at the most inconvenient time.

The cost of repairs must be considered. While in small plants it is perhaps advisable to send to a repair shop, it is usually better and cheaper in the end to order all repair parts possible direct from the maker of the plant. In a large plant the question of installing a repair shop with the necessary machine tools is worthy of consideration, and has many advantages, especially in cases of breakdowns requiring prompt and efficient attention. The state of the plant largely depends on the manager himself. If he has the necessary practical knowledge, he is able to get first hand information, but many have not the knowledge to fit them to supervise repairs, and in this case they will find it far better to employ someone in whom they have full confidence.

Insulation. This is very important in a cold storage plant, and raises many problems, especially where the building has old insulation which, owing to dampness or settling of material, is probably almost useless for the purpose. Bad insulation means endless trouble and largely increased working costs. Therefore, where materials such as sawdust or silicate cotton are installed, periodic tests must be made. Here the manager is faced with a problem which has to be attacked. He must, by proper tests, determine what bearing inefficient insulation has on his working expenses, and then go into the question of the cost of re-insulation. Before this can be started he must arrange that certain space will be available for the work to proceed, and after investigating the various methods of insulating, decide which is the most suitable for his purpose, and whether the work shall be done by contract or by the works own staff. If the re-insulating scheme is a large one, it is well worth considerable thought as to whether it would not be better to collect together some practical men, buy the materials in the best market, and do the work by direct labour. This course has many advantages, because conditions and demand for storage vary from time to time, and it is not always convenient to arrange matters so that a contractor is not subject to delays which always mean expense.

Improvements in refrigerating plant and practice are always being introduced, and close attention is required to see whether these can with advantage be applied. There is a general tendency to go on from year to year, being satisfied with the plant as it is, knowing it can be improved, but putting off the improvements until better times. This is a fallacy, for in most instances money is being lost by not keeping the plant up to date.

Running. Once the plant is in efficient order, the question of economic running must receive attention. Rule of thumb methods will not give the results which should be attained, and a manager with the pride of his profession in him will not be satisfied until he is convinced that the plant is running as economically as possible. Various instruments are of service to him here, and can in most instances be usefully employed. In a steam driven plant there should be a CO_2 recorder, preferably one giving a twenty-four hour record on a chart. This is of great assistance in keeping a watchful eye on coal consumption, and the results which can be reached with the aid of this instrument are often surprising. The boiler house staff must be interested in the average percentage of CO_2 in the flue gases, and encouraged to vie with one another in getting the best results. These results should be rewarded in a tangible manner. If, by proper attention to the boilers, coal consumption is reduced and kept at a low figure, then a bonus should be paid to the firemen. This is surely the right and proper encouragement to give.

A method whereby the amount of water evaporated in the boilers per twenty-four hours is recorded should be installed, as well as a meter on the water service supplying make up losses of condensing water. By these means the water evaporated per pound of coal burned, and the percentage of make up water can be ascertained. If this, in the former case, is too small, or in the latter case too large, the reason must be looked for and rectified.

Indicators, for both steam engines and compressors, should be used regularly and the results carefully studied. The question of taking the temperatures in the different cold chambers has a distinct bearing on the economic running of the plant, and long distance electrical thermometers with the switchboard fixed in the engine room is a most useful installation. These thermometers are now made to give reliable readings to within 0·5° F. of accuracy. In a large store, this instrument not only saves the time, otherwise taken, by a man going round reading the ordinary thermometers hanging in the chambers, but also renders it unnecessary for him to open and shut the chamber doors when doing so. It must be remembered that each time this happens there is additional work for the plant to perform. The installation has still further advantages; the man actually running the plant can so regulate the valves that he is able to reduce work which is not being usefully performed, the matter of temperatures is under one control, and furthermore the manager himself can easily check them at any time.

The Cold Store Superintendent. There should be very close working between the engineer and the cold store superintendent, and the manager should see that this is so. The arrival of consignments of goods, their condition and temperature when received, the chamber in which they are to be stowed, the chambers which are to be cooled, or laid off for defrosting or cleaning, are all points which can be discussed by these two employees with great advantage.

In the cold store itself the main question requiring attention is that of labour. In comparatively small stores this is more easily provided for, and a permanent staff can be engaged; but in a large store, especially where the labour is "casual," the problem and its relationship to working costs is a more difficult one. First there must be the permanent staff which varies in number according to the size of the undertaking. In a small store the manager is more often manager, engineer, store superintendent, and chief clerk all in one, and can give his personal attention to the details of all departments. A large store requires a stores superintendent to supervise that part of the business in itself, and quite possibly he may require an assistant superintendent and several foremen. The superintendent then must be capable of handling labour to the best advantage. Where it is mostly "casual," as in large port stores, he must arrange that the number of men employed is not in excess of the number required to handle the goods in or out of store, in any one four-hour shift. He must provide the space required in the chambers which are kept at the proper temperatures, and must see that the different consignments are in a satisfactory condition when received. He must also note any meat or goods which arrives in a damaged or soft condition. The condition of all goods when received is a most important point, for if, due to carelessness on the part of an employee, a clean receipt is given when it is not due, the manager is faced with trouble and annoyance to all concerned when the goods are delivered, and more often than not has to meet a claim. For instance, carcases of mutton which arrive in soft condition, due possibly to delay in rail transit, must not be stowed in bulk pile but have to be laid out in single tier until hard frozen, and then piled—this means extra space and extra handling for which a legitimate charge can be made. Meat and other goods must, on arrival, be got into the chambers with as little delay as possible, and stowed to marks, so that they are readily accessible for delivery. Each parcel should be labelled with the date of receipt and the merchant's name. It is also an added advantage to show the source of receipt, whether by rail or road transport, or if by sea, the vessel's name. "Marks," while not quite so difficult a problem as in years past, still cause trouble, for each parcel must be kept separate, and this often means a number of small piles of meat, involving a large waste of storage space.

All goods must be carefully checked as to quantity, marks and submarks, or confusion or worse, will arise when deliveries are called for. Where general storage is provided for, say, meat, both frozen and chilled, eggs, butter, fruit, hops, etc., the proper conditions of stowage for each commodity, the temperature and humidity all have to be considered, and arrangements made to accommodate the goods as they arrive. A point to be insisted upon is that the storage chambers must be kept clean and sweet. Cleanliness in a cold store is a necessity, and one of its finest advertisements. A manager should see that this question receives the attention it deserves, and it should be one of his first duties to make sure that any foodstuffs entrusted to his care are treated and stored in as cleanly a manner as possible. One of his enemies is the growth of mould, and this can be defeated by systematic and regular cleaning of the chambers.

Goods are weighed either on receipt or delivery, or both, and in addition to this the manager is often called upon to weigh parcels of produce when they are transferred from one merchant to another. This work necessitates having reliable weighing machines. Every care should be taken to ensure that accurate weights are given, and so avoid disputes and unnecessary worry. In the office a proper system of keeping stock books, the issuing of delivery orders to the stores superintendent, account keeping and rendering, all require to be organized.

Managerial Duties. What, then, are the problems which daily require the personal attention of the manager ? How should these be tackled, and what are the best means to secure smooth and successful running ? First will come the organization and the collection of a staff in whom he has full confidence and, just as important, who will have confidence in him. He will choose, as heads of the three main departments, engineering, stores, and office, men who can be depended upon to carry out instructions and 'see to the details of their respective departments. Through these assistants he will endeavour to create an interest among all employees ; in other words, he will institute team work, each man doing his particular duty willingly and to the best of his ability. Promptness in business should be the keynote. It should begin at the very beginning, and be carried through all details such as obtaining the goods, storing them under the right conditions, delivering them, rendering and collecting accounts for storage and other services, and paying the accounts of the business itself.

First in the daily routine will come the correspondence containing orders for delivery, inquiries as to space, cold storage rates, and possibly complaints—the last item should have personal attention to see if there is any justification for it having been made. If so, steps must be taken at once to put the matter right and avoid a recurrence. The letting of space will entail considerable thought, for it may well be that a decision has to be arrived at as to whether it is wise policy to accept the goods offered, or decline them and take the risk that more profitable business may come along in the near future.

After correspondence has been dealt with the three chief assistants must be interviewed, to report on their departments and receive instructions. How best can the manager keep in close contact with the details of the business, and know at any time the earning capacity of the undertaking? The best constructed and most modern plant may soon become expensive, erratic in performance, and possibly a liability to its owners, unless those in charge realize how essential it is to keep records and compile statistics, under different headings, which provide a check on expenditure, and show the earning capacity under the varying conditions to which cold storage is subjected. Each store should then devise some system of daily reports dealing with—

1. **Stores Department.** This should give: (*a*) an accurate return of the amount of goods received and delivered during the previous twenty-four hours, with details of the different classes of goods; (*b*) a labour return showing the number of men employed; and (*c*) a weekly return showing the amount of space available.

2. **Engineer's Department.** (*a*) A daily engine room log sheet, giving full particulars of working and any repairs executed; (*b*) a daily temperature sheet giving not only the temperatures in each chamber, but the class of goods stored therein; (*c*) a weekly return of quantity and cost of all stores consumed; and (*d*) as many other reports as may be considered necessary.

All of this information should be dealt with in the office daily and in a systematic manner. Everything to be of any real use must be kept up to date, so that should any question arise as to temperatures, goods in store, coal consumption, or the hours the plant has run, the answer can be secured in a few minutes.

3. **Finance.** With the foregoing data supplied to the office

by the operating departments, the system should provide for a financial statement at stated periods. The revenue account should show how the revenue has been obtained, and give particulars of earnings from the different classes of goods stored. The operating accounts should give full details and information under headings of operation, i.e. engine room expense ; storage, i.e. labour in the store itself ; maintenance, i.e. of machinery and buildings ; and general, i.e. salaries, office expenditure, rent, rates, taxes. All of these can be split under as many different headings as may be considered necessary. There will then be a summary sheet to which is transferred total revenue, and from which working expenses are deducted, leaving the surplus made during the period under review. In addition to this there should be a statistic sheet for both the engineering and storage side of the business, and each classification of accounts should give, for comparison, the amounts and figures for the corresponding period of the previous year. These figures can then be analysed to show tonnage received, delivered, and handled ; tonnage handled per man per hour ; cost per ton for labour, supervision and rehandling, etc., covering cleaning of premises, and the cost to refrigerate a ton of goods, divided under cost of operation, maintenance, general, etc. With these figures at his disposal the manager knows with great accuracy what is the total cost per ton. He will find this information of very great assistance in keeping a constant check upon expenditure, and a considerable help in fixing the rate to be charged for performing the service he has to provide for his customers.

There has been, in the past, a feeling, on the part of the operators of cold stores, that such a system is not necessary for their industry, or if so it is an evil to be put up with. Comparative statistics will be found of great interest and value, and the manager would be wise to insist upon having available at his hand always, comparisons by years, months, and weeks, of tonnage in store, receipts and deliveries, labour returns, earnings, etc., and for easy reference he can prepare graphs showing these details. Statistics are useless unless they are used, and they become more valuable the longer they are kept. They govern the method of operation, and if action is not taken where costs are found to be excessive, there is no object in compiling them. The manager who has such a system need never be afraid of a competitor who does likewise, it is the competitor who works in the dark and quotes rates off hand who causes all the trouble.

The well being of employees should be considered, and proper mess room accommodation and conveniences should be provided ; while if the staff is a large one, some system of a sick benefit fund is worth thought and encouragement.

New methods of storage are continually being introduced, and investigations into defects and their causes are constantly taking place. The manager who wishes to keep up with the times will study the technical papers, and by becoming an active member of his particular association, will meet men with difficulties and problems like his own. The discussion and exchange of ideas and experiences with these men will enable him to increase his range of knowledge and the usefulness and standing of his industry. Publicity is a subject not to be neglected, and by giving opportunities to the general public to inspect his premises, and particularly by arranging for members of any engineering society or parties of school boys and girls to visit his cold store, he will perform a useful service, and help to build up confidence in an industry which, considering its importance to the masses of the general public, is so little known and understood.

Moulds and Fungus

From 1917 to 1919 a good deal of trouble and loss was occasioned to the meat trade by the appearance of "black spot" on shipments from Australia, New Zealand, the Argentine, and other countries. An investigation into the cause of this was carried out by the Food Investigation Board.* The conclusion was reached that it was due to the unduly long storage, occasioned by the war, in the countries in which the meat was killed and frozen. It was also found that "black spot" is the fungus *cladosporium herbarum,* which is common on decaying vegetation, and that it can grow at temperatures above 18° F., though at the lowest temperature growth is very slow. Its growth on meat above freezing point is also slow, not because of the temperature, but because at these temperatures it is smothered by other bacteria which do better. The best temperatures therefore for development are just below freezing, especially when, as it is likely to do under these conditions, the temperatures fluctuate. The fungus produces no poisonous substance at any period of its existence, and infected meat is not dangerous for food so long as it is not also infected by putrefactive bacteria. The growth of the mould is quite superficial, and it is recommended that if a store has become infected it should be disinfected by fumigation and washing with a solution of Condy's fluid.

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* Food Investigation Board Special Report No. 6, 1921. The "Black Spot" on Chilled and Frozen Meat.

Other moulds which have from time to time appeared on frozen meat, rabbits, etc., and have given rise to loss and anxiety are *mucor mucedo* and *penicillium glaucum.* Moulds are on the border line between a plant and an animal and are really a parasite, taking their nourishment from the host on which they grow. The spores are fairly ubiquitous, and only require a suitable host and suitable conditions to grow freely. Their germination and growth are materially affected by temperature. At normal temperatures it is rapid; at temperatures well below freezing it is generally considered that germination does not take place, though once germinated growth will continue slowly even at the temperatures used in cold storage and in the carriage of refrigerating produce on board ship. *Penicillium glaucum* is the mould which is commonly found in hams. *Mucor mucedo* grows there also, but is more commonly found on dead meat, and is particularly partial to frozen rabbits. Like *cladosporium* and *aspergillus glaucus* and its other varieties, they are both free from toxic qualities. The best way of guarding against these moulds is to keep the stores and ships' holds clean and avoid fluctuations in temperature. When produce after being frozen has to be conveyed for a long distance in railway cars, which are insufficiently iced or not iced at all, it is liable to get surface thawing which will produce dampness. If the spores settle on this damp surface they may germinate, and will continue to grow slowly and spoil the appearance of the produce, even though it is subsequently reduced to a temperature well below freezing. Similarly, produce may be placed in a cold store next to a weak spot in the insulation, through which heat can enter. Normally this spot may not have been noticed, but the heat will cause surface softening with, possibly, a consequent growth of mould. Again, produce may be placed on board ship in a perfect condition, but if it is packed near the hatchways, which are opened at another port to admit more cargo, the warm air may cause surface dampness, either by partial thawing or by condensation of moisture on the cold surface, and this may give rise to a growth of mould.

CHAPTER XII

ARTICLES IN COLD STORAGE

THE Public Health (Preservatives, etc., in Food) Regulations of August, 1925, made by the Ministry of Health, came into operation in England and Wales in 1927 and 1928. Similar regulations made by the Scottish Board of Health apply to Scotland.

These prohibit the sale of any article containing preservatives except sulphur dioxide and benzoic acid, which can still be added in the minute quantities which are set out in the first schedule of the Act.

In England and Wales the addition of any thickening substance to cream is prohibited. Certain colouring matters are blacklisted and may not be used. Sausages, sausage meat, coffee extract, pickles and sauces, and in certain circumstances grape juice and wine will require labelling with a regulation label stating that the substance contains preservative.

The principal argument in favour of preservatives in the past has been that their presence and effects were less objectionable than the deterioration which, in their absence, takes place in the average larder. This is not a really sound argument as, although some of the accompaniments of decomposition are held in check by the presence of the " preserving " agent, modern science has revealed that the treatment of food with chemical preservative may, in fact, only be masking putrefactive changes in the structure of the commodity which are highly inimical to the health of the consumer. It is obvious that, deprived of the aid of preservative substances which have hitherto been very widely used in foodstuffs, manufacturers, retailers, and users must take other steps to prevent the too rapid deterioration of their foodstuffs that would otherwise occur.

Refrigeration is the only alternative method of preserving of which we have present knowledge or can foresee, so that the new Regulations have enhanced the importance of cold storage.

Many manufacturing firms, taking time by the forelock, are giving up the use of preservatives in good time, and have already called refrigeration into use in their stead. The general effect of the Regulations will be to add very greatly to the numbers of small machines in use for both trade and domestic purposes, and still more, to the general adoption of preservation by ice in ice chests, as in the United States.

More important still, the official exhortation to the nation to avail itself more fully of cold storage must have a far-reaching influence in the tightening up of services—notably that of railway transit of highly perishable foods. This railway transport has hitherto been a very weak link in the chain of protection necessary for all " perishables " on their way from the point of production to the consumer, and it is for this reason, principally, that so much perishable produce is now sent all over the country by fast and direct motor lorries.

§ 1. Butter

The proper storage temperature is 10 to 12° F. In England shipments of butter are constantly arriving from Denmark, Holland, Canada, New Zealand, Cape Colony, South America, and Russia. There is thus a continual inflow throughout the year; the New Zealand season, for instance, being in full swing when the Canadian is quiescent. There is thus a constant demand for cold storage, though owing to the regularity of the supply the period of storage is not usually long. While butter stores well, it is undoubtedly at its best when it is first made.

The temperature given of 10 to 12° F. is about the usual figure for voyages or for long storage of, say, eight to nine months. In some cases a temperature as low as zero F. has been used. For storage of a few weeks' duration only, a temperature of 30° F. is quite satisfactory.

Butter should be stored in the tubs and boxes just as it arrives, these being packed one on top of the other. With tubs the interspaces will provide sufficient area for air circulation, but battens should be placed between the boxes.

Professor Lauterwald* draws attention to the adverse influence of strong light on the colour and flavour of butter and advises that it should always be kept in the dark or, if exposed to light, the windows should be red, yellow or grey, never green, blue, or uncoloured.

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* *Der schaedliche Einfluss des Lichtes auf die Qualitaet der Butter. Molkerei Zeitung*, 1923.

Butter is exceedingly sensitive to foreign odours, and should be stored entirely by itself, care being taken that the room is absolutely sweet before it is put in. There is a small generation of gas, and occasional ventilation is desirable.

The boxes and packages must, of course, be of white wood which has been well seasoned to eliminate any odours.

§ 2. Cheese

Cheese stores at 35 to 40° F., it follows much the same rules as butter and should be stored in a room by itself. Ventilation is desirable. It should not be frozen or it will become short and crumble. The humidity of the room should be such that the cheese is kept from shrinking or cracking, but it should not be so great as to allow mould to set in. The actual humidity required is probably about the same as that for eggs.

Both in Canada and New Zealand it has been found that control of the temperature of the curing rooms in cheese factories by means of refrigeration is of great advantage. With a curing room cooled to a temperature of 45 or 50° F., not only is the loss of weight that would otherwise occur approximately halved, but the quality is appreciably improved so that a higher price is obtainable for the cold cured cheese.

§ 3. Eggs

Eggs are undoubtedly exceedingly sensitive and rapidly absorb odours and smells. While an egg is alive it is always giving off gas, and in small rooms this should be removed as soon as it is formed, or fungus will form and the egg become musty. If, however, the room in which the eggs are stored is of large capacity and the doors are being opened fairly regularly, the ordinary diffusion of gases will be sufficient to prevent any bad results from this cause. The egg storage room must be constructed of specially odourless timber, or the timber must be varnished or painted so that its odour is killed. It is best cooled on the combination system by brine pipes and air, or by air alone. It is essential that a gentle circulation and ventilation should be kept up to remove the gas and moisture given off by the eggs, and to prevent the formation of white fungus or mildew. Eggs should never be stored with other produce.

Opinions have been expressed that air circulation, and particularly the introduction of fresh air, is not necessary for egg storage even for long periods. To settle this point, experiments* have been carried out in the United States by Miss E. Pennington in keeping eggs under three sets of conditions, the object of the experiment being to try and ascertain whether a continuous or intermittent current of fresh air will delay or prevent the development of moulds, foreign flavours and odours in eggs when packed in the standard egg case with standard fillers, flats, and pads.

Temperatures between 29 and 31° F. were maintained continuously.

Room A was not ventilated. Rooms B and C received about 10 cu. ft. of air per minute, but the air admitted to B was cooled by 20° brine, while in C it was cooled by 10° brine. After about seven months' storage the comparison of the three rooms was as follows—

	Room A	*Room B.*	*Room C.*
Relative humidity . .	83%	82·1%	91·9%
Loss of weight . . .	3·74%	3·86%	3·48%

The eggs in Room A (not ventilated) had grown well developed "whiskers" in practically every case examined.

In Room B there was a slight "fuss" (i.e. mould, the start of "whiskers") on the centre layers; while in Room C no mould or "whiskers" were found. After two weeks' aeration with larger quantities of fresh air, there was no further development of "whiskers" in Room A, and the "fuss" in Room B had disappeared.

The conclusions drawn are that aeration with fresh air had a deterrent action on the absorption by the eggs of storage flavours, that moving air does not accelerate the usual shrinkage of stored eggs, provided that the air be sufficiently humidified, and that a handsome growth of " whiskers " and an incipient growth of mould can be checked by fresh air. The total loss in weight averaged about 0·5 per cent per month, which agrees with the observation of other investigators.

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* See *Ice and Refrigeration*, June, 1923.

Further investigation* by Doctor Pennington and Mr. G. A. Horne into the conditions and results of cold storage of eggs, is summarized as follows—

1. Eggs with cracked shells in storage rooms, having temperatures between 29 and 31° F., and with air circulated by a bunker system, showed a retarded growth of moulds as compared with a similar room in which there was natural air circulation only.
2. The continuous operation of an ozone machine with the presence of about one part of ozone per million parts of air by weight did not influence the rate of mould development in egg storage rooms with bunker circulated air.
3. The continuous presence of ozone in the air of egg storage rooms lessens the absorption by the eggs of the odour of the commercial package containing strawboard fillers and flats.
4. There is a very close relation between the relative humidity of the air of the storage room and the loss of moisture from the eggs, in which the package participates.
5. The ability to regulate the humidity of the air of the storage room at will may lead to the maintenance of higher average humidities to avoid excessive loss in moisture, especially if the rooms are supplied with artificially circulated air.
6. The upper safe limit of relative humidity under the above conditions has not yet been determined, but it is certainly above 80 per cent.
7. There was no visible growth of mould, either by inspection or candling, after holding eggs for five months at an average humidity of 84·3 per cent in a room with bunker circulated air.

For storage purposes the eggs should be collected at the latter end of March and in April and May when they are nest, most plentiful, and in the most healthy condition. Eggs gathered in the summer are liable to be affected with heat spots ; these are small light coloured spots which form on the yolk, and though an egg affected in this way need not necessarily be bad, it is unsuitable for cold storage and should be rejected.

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* Vol. 1, Proceedings, Fourth International Congress of Refrigeration.

Before being packed the eggs should be carefully sorted, graded, and candled. They should be again candled before they leave the store for the market, though in practice this is seldom done. The packing cases are best made of some white odourless wood, such as spruce or poplar. Before the box is nailed down, a layer of coarse granulated cork or similar material should be put in to act as a cushion between the eggs and the covers. A material known as "Excelsior" is much used in America. It is made out of basswood shavings, and should be kept in stock some time before use, in order that it may get seasoned and lose its odour.

Eggs for cold storage purposes should never be washed, as this removes a fine coating resembling varnish which naturally covers the shell and renders it less porous. If this varnish is removed, air gets to the meat and the process of decay becomes rapid. Unfortunately it is very difficult to tell a washed egg from an unwashed egg. The cases containing the eggs should be stacked in tiers with laths between them; this makes an air space round each case and allows efficient ventilation to take place. With the same object the cases are sometimes made with the sides an inch narrower than the ends.

It is generally agreed that the best temperature for the storage of eggs for long periods is 29 to 30° F., though for short periods it may be as high as 38 to 40° F., provided that the humidity is properly controlled. If the temperature falls below 28° F. the yolk becomes hard and the white freezes. At 30 to 32° F. the egg is in its normal condition with the white slightly thickened, and this helps to keep the yolk central.

It will have been gathered from the foregoing that one of the most important matters in the successful storage of eggs is the retention of the atmosphere at the proper degree of humidity. If the air is too humid the eggs will go mouldy; if too dry they will give up their natural moisture and shrink as much as 20 per cent. At 32° F. a humidity of about 70 per cent is about right. Mr. Maddison Cooper, who has devoted considerable attention to the subject, gives the following list of the proper degree of humidity for egg rooms—

Temperature in Degrees F.	*Relative Humidity, per Cent.*
28	80
29	78
30	76
31	74
32	71
33	69
34	67
35	65
36	62
37	60
38	58
39	56
40	53

The humidity can easily be ascertained by a wet-and-dry bulb thermometer.

When taken out of storage the eggs should be gradually tempered to prevent any deposition of moisture on them from the warm air with which they are brought in contact, and as a precaution against this the cases of eggs brought out from the cold storage rooms are often placed in another room, through which a very vigorous circulation of air is maintained by means of a fan to prevent the formation of any such moisture.

It is important that only first-class eggs should be collected for cold storage. They should be carefully sorted, graded and candled, and put into cold store as early as possible. There are several methods of determining the conditions of eggs—by candling, by density, and by the general appearance of the shell. Of these, candling is the most reliable. The apparatus generally used consists of an ordinary incandescent lamp fixed in a rectangular or cylindrical box. Two holes about 1¼ in. diameter are pierced in the sides. The bottom of the box is often left open to illuminate the table underneath, on which the trays of eggs for testing are placed.

In candling the egg is taken up with the thumb and first finger and held close to one of the holes. Wholesome eggs are very transparent—darker ones require further investigation. If there is a dark patch the egg should be immediately rejected. In Denmark, eggs to be examined are placed over holes in the bottom of a perforated tray. The tray, laden with eggs, is then passed over an open-topped box which is strongly illuminated inside. The examiner can then very quickly inspect a large number of eggs at a time and remove those in which there are defects. The tray is passed on to an operator who removes the eggs and places them in packing cases. The empty tray is returned for refilling, and with a number in use, the process becomes continuous. Eggs of which the shells are cracked should not be cold stored, but can be used for breaking and freezing in bulk. Eggs with dirty or cracked shells which are not required for immediate consumption are generally canned and frozen; the shell is broken and the egg meat may either be mixed up and frozen as a whole, or the whites and yolks may be separately collected and frozen. Whichever process is adopted the egg meats are filled into tins, from which the air is exhausted before sealing up. The tins are then taken to a freezing room and frozen solid. In this condition the contents will keep practically indefinitely. They should, however, be used without delay on opening, and are largely employed in the manufacture of confectionery.

Apart from their more proverbial uses, rotten eggs are largely used in tanning. In large factories they are generally collected and frozen so that a regular supply can be arranged. Eggs are also preserved by freezing in their shell. If this is done without any previous preparation the shell often cracks as a result of the expansion of the contents when freezing.

It is not always the case, and the story is told of a man who was shown for the first time a frozen egg being thrown against a wall without breaking. Thinking to surprise his wife, he put one in his pocket and when he got home at the end of the day he took it out of his pocket, and saying " Look, dear," threw it against the papered wall of the drawing room. In the interval, since leaving the store, the egg had thawed with the warmth of his pocket, made a horrid mess on the wall and—dear looked !

Cracking can be prevented by evaporating their water content by about 5 per cent before freezing. Unless care is taken to hold frozen eggs at a temperature *at or above* the point at which they are frozen—which should not be lower than 23° F.—the consistency of the white and yolk will change and will not revert to their original condition on thawing.

§ 4. Furs and Fabrics

The proper temperature for these articles is 30° F. The primary object of cold storage for furs is to prevent the hatching of the minute eggs of the tailor moth. If furs are not cold stored in hot weather they should be examined, beaten and shaken at regular intervals. In spite of considerable attention given in this way and the use of materials such as camphor, it is very difficult to obtain freedom from damage by the grub.

There are now many fur stores in existence, some of them of considerable extent. The same cold storage is also used for the preservation of valuable fabrics and furnishings. Apart from preventing damage, cold storage actually improves the appearance of furs, as the natural oils in the skin which give it its suppleness and gloss are apt to evaporate in hot weather, but are preserved by the low temperature.

The cooling should be carried out by air circulation. The coolers should be of the dry pipe type, as damage from brine has been reported in cases where exposed brine circulation has been used, though this may actually have been due to faulty design.

§ 5. Dried Fish

Dried and smoked fish which has to be kept for any considerable time should be placed in cold store. For short periods a temperature of about 35° F. is sufficient, but for storage of more than a few weeks the best results are obtained by maintaining the storage room at about 15° F. The method of cooling by air circulation is found to give the most satisfactory results.

§ 6. Fruit

The success of any steps which are taken to preserve fruit depends much more on the knowledge of the fruit grower and packer, assisted by the scientist, than it does on that of the refrigerating engineer and architect. Until the growers have made up their minds to be guided in the kind and quality of the fruit they grow, the way they grow it, the time at which they pick it and put it into cold storage, and the way in which they pack it, the refrigerating engineer, even if he designs a perfect installation, cannot hope to achieve complete success, because he will be dealing with an imperfect article, imperfectly grown, imperfectly harvested and imperfectly packed.

It will be useful at this point to discuss briefly the chemical changes which fruit undergoes when ripening, and how the regulation of temperature can affect it. The fruit which has been most studied is the apple, and investigations have shown that the disintegration of the carbohydrates in the process of ripening involves, by respiration, the production of CO_2. The more rapid the respiration the quicker the time of ripening and the shorter the time of keeping, and conversely, the slower the rate of respiration the longer the time of keeping.

Gore* suggested that the CO_2 evolved by a unit weight in unit time should be the measure of velocity of ripening, and gave the following table--

RESPIRATION NUMBERS OF CERTAIN FRUITS AS AN INDICATION OF THE RAPIDITY AT WHICH THEY RIPEN

Species	Variety.	Respiration Number (at 0° C. in Milligrams per Kilo).
Blackberry	El Dorado .	30·9
Strawberry	Gandy . .	17·8
Plum	Wragg . .	6·5
Apple	Missouri Pippin	4·6
Orange	Valencia .	1·8

The deduction from this table is that while blackberries and strawberries have a very rapid rate of respiration and, therefore, a short keeping time, the plum is only a little faster than the apple, and consequently might, if suitably packed, keep well in cold storage.

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* Bigelow, Gore, Howard Studies on Apples; U.S. Bureau of Chemistry, Bulletin 94; 1905. (*See* also Bulletin 142, 1911.)

Gore carried on his experiments at various temperatures, and found that the relation between temperature and respiration agreed very closely with Van Hoff's law, i.e. the maturation velocity at 46·4° F. is double that at 32° F., and at 60·8° F. four times that at 32° F. Experiments carried out in France in 1912 agree with this.

Apples. The United States Department of Agriculture and the Department of Agriculture of the Dominion of Canada had fully investigated apples in relation to growing, harvesting, packing, and cold storage before people in England even began to think about the subject. After the formation of the Food Investigation Board at the conclusion of the war, and the construction of the Low Temperature Research Station at Cambridge, British research—ably directed by Sir William B. Hardy, F.R.S.—came on with a rush, and in the last ten years, has carried out investigation and secured results of enormous value. However, as regards the apple, it is impossible, at this stage, to do better than quote from Bulletin No. 587*—

> For a proper understanding of the behaviour of apples in storage it must be kept clearly in mind that the apple, like all fruits, is a living organism and that its life cycle, which begins in the blossom, ends under natural conditions in the death and decay of the fruit. When the fruit is picked from the tree its life processes do not stop. On the contrary, at ordinary temperatures, they continue as rapidly or possibly even more rapidly than before. The function of cold storage is primarily to retard these life processes. Its purpose is also to retard and prevent the germination of spores of fungi which cause the fruit to decay, and to prevent the development of skin blemishes. For this purpose a temperature of between 31 and 32° F. is considered standard for the apple. No temperature, however, which will not seriously injure the fruit by freezing can entirely check its ripening processes or the growth of all fungi which cause decay. It is obvious, therefore, that fruit allowed to become over-ripe prior to storage can never regain in cold storage the quality and vitality it has lost. Neither can cold storage prevent the final decay of fruit already infected with decay fungi. Since cultural and handling methods largely determine the

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* "The Handling and Storage of Apples in the Pacific North-West," by H. J. Ramsey, A. W. McKay, E. L. Markell, and H. S. Bird. United States Department of Agriculture, Government Printing Office, Washington, D.C., 1917.

condition of the fruit when it is stored, the first responsibility for its successful storage lies with the grower and shipper. . . . The individual growers should study their own fruit and their own conditions and whenever possible should make experiments to determine the stage of maturity at which the varieties they grow hold best in storage. The colour of the seeds gives some indication, yet in spite of many opinions to the contrary it is an unreliable index to the maturity of the fruit. Many factors may cause the colour of the seeds to vary without affecting materially the time at which the fruit reaches full maturity. The blush or red colour of the apple taken by itself also is unreliable. Both of these factors should be taken into consideration, however. Perhaps the most reliable single indication is the "ground" colour of the fruit; that is, the colour which underlies the red colour or blush. The "ground" colour, which is green when the fruit is immature, begins to whiten or yellow slightly as it approaches full maturity. . . . As a rule, in a mature apple the green colour should be largely replaced by a white or light-yellow colour. A dark yellow, on the other hand, usually indicates over-maturity. Allowances, of course, should be made for the natural colour of the variety, the amount of exposure to sunlight, etc. Experience will enable a grower to give the proper weight to each one of these factors and properly to co-ordinate them.

Dr. Ezer Griffith, writing in *Cold Storage*[*] gives the relative production of CO_2 by Bramley Seedling apples during their cold storage life—

	At 2·5° C. (36·5° F.)	At 10° C. (50° F.)	At 22·5° C. (72·5° F.)
Rate of CO_2 production when gathered	18	39	100
Maximum rate of CO_2 production during storage . .	30	55	161
Time, in weeks, taken to reach the maximum rate. . .	26	4	1
Storage life, in weeks, of sample	54	40	9
Rate of CO_2 production at end of storage life . . .	20	32	64

The factors governing the keeping of apples in cold storage in the order in which they occur may be summarized from various authorities as follows—

(*a*) *Variety.* This should be the result of careful selection, having regard to locality, soil, and conditions. Some varieties are more liable to scald than others.

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[*] *Cold Storage and Ice Trades Review*, January, 1923.

(*b*) *Orchard Practice.* As the uncoloured, and therefore immature, portion of an apple is peculiarly liable to scald, and as high colour is important for market reasons, it is very necessary to prune the trees so as to admit light and air into the interior to evenly ripen and colour the fruit.

(*c*) *Harvesting.* Scald is the commonest form of damage and cause of breakdown. The skin of the fruit browns and blackens as if it had been scalded. The flesh under the skin is not affected in the first instance. Brown heart is the term used to describe the brown and dead tissue in the flesh of the apple below the skin. Scald is external or a "skin disease." Brown heart internal or a "flesh disease." Bitter pit is similar in type to brown heart, but occurs on the growing apple generally under the skin.

Scald is induced by—

(*a*) *Immaturity.* One side of an apple may be mature, the other green or immature, the immature side will scald. Apples harvested early are, for this reason, peculiarly susceptible. With later harvesting and more mature fruit scald is comparatively slight.

(*b*) *Time of Storage.* Apples put into cold storage immediately after harvesting are much less liable to scald and decay than those kept for a fortnight or so in ordinary temperatures. Even a few days in the orchard or packing house may greatly shorten their cold storage life from decay, especially if the weather is warm. Few factors are of greater importance, and apples stored immediately after picking have held in cold storage, in good condition, one month longer than the same apples which were kept at ordinary temperatures before being stored.

(*c*) The absence of oxygen in storage, but it should be noted that the conditions necessary to the production of brown heart will not necessarily produce scald.

Brown heart is induced by—

(*a*) *Excessive accumulation of CO_2* when in storage due to absence of or insufficient ventilation. It is not caused by shortage of oxygen alone, or by CO_2 alone in the absence of oxygen. The presence of the two gases together appears essential. Experimentally, under gas storage conditions, 13·6 per cent is the lowest concentration of CO_2 associated with the occurrence of brown heart.

It can be produced in less than three weeks after storage commences.

(*b*) *Absence of Precooling.* The time taken by an apple to produce CO_2 equal to its own volume varies with the temperature (*see* Table on p. 375). At 34° F. it is not less than fourteen days, at 50° F. it is not less than seven and a half days, at 70° F. it is not less than forty hours.* Consequently apples stored hot continue to produce CO_2 at the maximum rate until they are cooled down. Apples which have been precooled before shipment have not been affected with brown heart even in an unventilated hold.

(*c*) *Harvesting.* Immature apples are more susceptible to brown heart than mature apples.

(*d*) *Variety.* Different varieties of apples produce CO_2 in greater or less degree at any given temperature. Liability to brown heart has been found to vary with different varieties, and with the same variety grown in different localities.

Decay is induced by—

(*a*) *Scald.* Scald weakens the skin of the apple and gives a point of entry for the fungus spores.

(*b*) *Bruising.* Physiological decay starts at the bruised or damaged part of the fruit. Not only is the appearance damaged by bruising but the life is shortened.

(*c*) *Over-Maturity.* A mature apple does not mean an apple which is ripe to eat. At this latter stage the fruit has received all its sustenance from the tree, and an apple which is in the best condition for eating is too ripe for cold storage. A short cold store life in this case will be due to physiological and fungus decays.

The following further quotation from Bulletin No. 587 should be of particular interest to oversea shippers to British markets. The remarks apply, of course, to the Pacific North-West and its markets, but the moral remains and is capable of a wider application:

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* H. C. Gore, F. Kidd, and C. West.

The need of prompt cooling has been strongly emphasized in connection with immediate and delayed storage. It is very evident that whether stored near points of production or several thousand miles distant, the need of prompt and rapid cooling is exceedingly important. When stored near the point of production every effort should be made to get the fruit into the storage house promptly. When intended for eastern storage the apples should be shipped in refrigerator cars under refrigeration. They should be loaded into pre-iced cars as promptly as possible after harvesting. As the average cooling of a full load of tightly packed and wrapped apples in a refrigerator car is comparatively slow at best, the need of getting the fruit under refrigeration promptly is even greater than if they were going directly into storage. Precooling is an efficient means of securing prompt and rapid cooling and should be utilized wherever facilities are available. Promptness of cooling is essential to good keeping quality, whether effected through precooling or in the car in which the fruit is shipped while in transit.

There are over 1,000 named varieties of apples, many of which are excellent fruit so far as they go, but very few of which are, for one reason or another, of any value commercially. The apple may be a perfect variety but may be imperfectly grown. The researches of Professors Theobald and Salmon have shown that, having selected the commercially best variety, the secret of fruit growing is spraying, and still more spraying. It is impossible to guard against everything, of course, and the spores of fruit pests are elusive ; but it stands to reason that an apple with a clean, unbroken and unscabbed skin will stand a better chance of keeping than fruit which is covered with fungus or canker, and is full of worm. Actually the case could be put a good deal more strongly than this, for a diseased apple is covered with spores which spread to the sound apples.

There is another point in harvesting which hardly requires touching on, and that is that the fruit should all be hand picked and unbruised.

Imperfect packing is the last of the points belonging to what might be called the grower's department to which attention should be called. In this connection is the way fruit grows on a tree, all spaced out along the branches, so that as nearly as possible each separate fruit hangs free and independent of its neighbour, properly considered ? and is it realized why it grows like this, and why a good gardener will thin out his choice fruit so that it is not too crowded on the stems ? The reasons, of course, are several in number: (1) To allow the fruit full room for development ; (2) to prevent it distorting its neighbour ; (3) to allow plenty of air to circulate round it. Fruit when picked in the ordinary way is shovelled into a box or basket, each fruit touching the next in no sort of order, no protection from bruising, and no room for air to circulate round it. How can it be expected under these conditions to keep fruit in decent condition for more than a short time ?

There are very few growers in this country who pack their apples in non-returnable boxes. Most of the fruit is sent to market in returnable bushel baskets, which is bad packing, for not only are the baskets the wrong shape for keeping the fruit in good condition, but they are full of spores which infect the fruit and set up decay. Packing in boxes necessitates grading. A carefully graded box of apples will always secure a better price than a case of all sizes arranged higgledy-piggledy. Growers should grade their apples, wrap them in oiled paper to prevent scald, pack them carefully in non-returnable boxes, so that they can go direct to market if the market is good, or direct to the cold store if it is not.

Growers should realize that cold storage will help them to hold their fruit in sound condition until the market can absorb it ; but they must realize that it can only do this if they are prepared to take some trouble to see that the fruit is in good condition when it is put into the store. This is the grower's part of the job, and if he does it he can safely leave the rest to the refrigerating engineer.

Granted that the refrigerating engineer can rely upon receiving at the cold store good, sound fruit of good keeping quality, well grown, well harvested, and well packed, he has to remember the following physical characteristics of the fruit and to design his store to meet them. These remarks apply generally to all kinds of fruit.

An apple, like an egg, is a living, breathing organism, and cannot be treated like a dead substance, as, for instance, frozen mutton. It has an average water content of about

83 per cent, and a freezing point which has not yet been definitely determined, but is probably about 29° F. It is known to be below 30° F., but it is, of course, not wise to store apples below this temperature. A temperature between 31° and 32° F. is the one generally recognized as best, and it is of vast importance that the temperature should not be allowed to fluctuate, but should be kept steady between these rather narrow limits. The Food Investigation Board quotes some experiments with Worcester Pearmain, an apple popular on the market for its colour, but not of much account otherwise. They were stored at 34° F. and 85 per cent humidity. When the temperature was raised to 41° F. and the humidity lowered to 60 per cent, shrinkage—as might be expected—occurred. The humidity figure of 80 to 85 per cent has been found to give the best results, and is generally accepted.

The author has come to the conclusion that the pipe loft system of cooling is the most suitable in stores which are specially built for fruit storage, and in which the machinery is only run for short intervals during the day time. If air circulation alone is relied upon the temperatures are liable to rise unduly during the time that the machinery is shut down. If direct expansion or brine pipes are placed on the ceiling there is trouble from drip, and the chilling of the fruit adjacent to them. If behind a curtain on the walls the circulation is too local, and is liable to be interfered with by the cases of fruit. On the other hand, if brine pipes of ample capacity are hung from the roof, and a false ceiling is placed below them, as in the curtain system referred to on p. 537, there is a natural circulation of air always going on so long as the brine pipes are colder than the air. Drip is looked after by the false ceiling, the upper side of which is made watertight and fitted with drip gutters.

A battery, provided with means for introducing a certain amount of fresh air at intervals, should be placed outside the rooms, and the air ducts should run vertically down the walls on either side of each room. The fruit should be stacked in rows, running at right angles to the flow of air, so that in circulating or in passing from the inlet to the outlet ducts the air has to pass through and round the cases of fruit.

A fruit store, built more particularly for the storage of apples, and cooled on the system just described, is illustrated in Fig. 136, which is a section through the store and shows the air-cooling battery in the roof, the 4 in. brine pipes in the pipe loft, the false ceiling, and the inlet and outlet air ducts. Fig. 137 shows the cases of apples kept apart by pieces of wood and stacked in rows at right angles to the current of air.

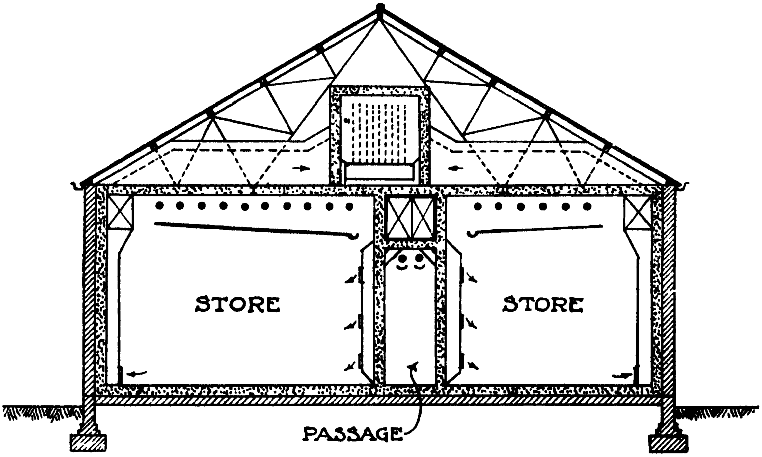

FIG. 136

Fig. 138, which was taken in an empty chamber, shows the inlet air ducts, which can be regulated by gearing from outside the room to admit more or less air as desired ; and Fig. 139 shows the air outlet, which is hand operated and placed near the floor on the opposite side, the cases being temporarily removed in order to show it.

A fruit store should be designed with rooms in which the packing space does not exceed 8 to 9 ft. in height to permit of easy handling. There should be, preferably, a precooling room of ample size in which the apples going into store can be cooled down to the storage temperature before they are introduced into the store itself. This will avoid raising the temperature of the fruit already in store above the level at which it is essential to keep it. The same room will be used for raising gradually the temperature of the fruit to that of the outside air when it is being withdrawn from store. This will prevent sweating and render the fruit more marketable

FIG 137

The interior of a fruit store should be rendered impervious to the absorption of the peculiar odour of the apple, which is most penetrating, and air which has circulated through an apple room should never be passed through a chamber containing any other kind of produce, or the odour will be picked up.

Unless the CO_2 produced by the fruit is removed it will remain in the store. The theory has been advanced by the Food Investigation Board* that the brown heart which has been so troubling the Australian trade is due to suffocation

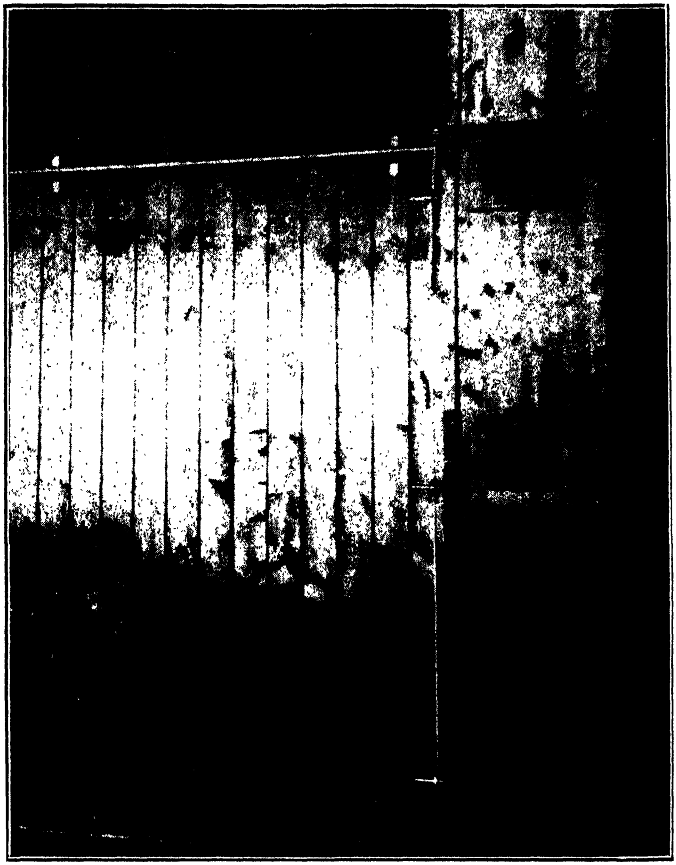

FIG. 138

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* Food Investigation Board Special Report No. 12: "Brown Heart a Functional Disease of Apples and Pears," by Franklin Kidd, D.Sc., and Cyril West, D.Sc. H.M. Stationery Office, 1923. 4s. 6d. net.

of the apple, caused by too little air circulation, too little oxygen, and consequently too much CO_2. Based on the gas storage experiments, which are so fully and ably detailed in

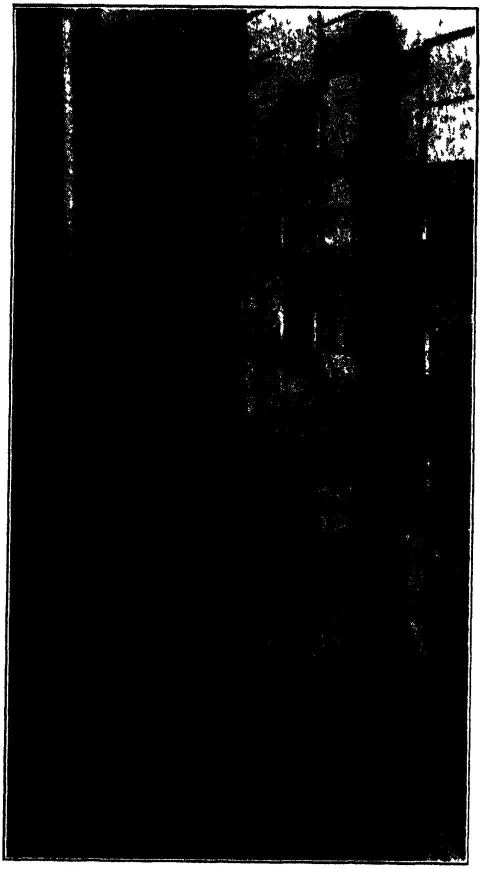

FIG. 139

the report, the theory appears tenable as the immediate cause, but the possibility of the trouble arising from pre-shipment defects, such as those to which the writers of Bulletin No. 587 attach so much importance, has probably not been overlooked, and it must not be forgotten that many cargoes of apples have been landed in this country from Australian ports in perfect condition. Attention has already been drawn to the fact that cargoes consisting of precooled apples were not affected. The practice of shipping apples in a warm condition does not appear to have much to commend it, and it would seem to be just as reasonable, in substance, to ship meat hot and trust to the refrigerating machinery in the ship to cool it down or freeze it. It is quite certain that whatever the constitution of the atmosphere in the apple room, it is essential for proper ventilation that the cases containing the fruit should be stacked, by means of packing strips, with an air space of from ½ in. to ¾ in. between them, top, bottom, and sides, as shown in Fig. 131, so as to permit the circulating air to play freely around them. It is absolutely fatal to stack the cases solid.

When apples are stored at normal temperature, the principal cause of death is by fungal disease, whilst at cold storage temperatures, the cause of death is usually a functional disease. The temperature which will give the best results is, therefore, that at which the combined loss resulting from both types of disease is at a minimum.

As has been stated, a temperature of between 31 and 32° F. is generally recognised as the best for commercial storage, but as the characteristics of different varieties of apples vary, it is obvious that when one species may preponderate, it might be of advantage to adjust the storage temperature to suit. Thus the Food Investigation Board has found, experimentally, that for Bramley's seedlings a temperature rather over 34° F. will probably have to be recommended, and a temperature of 36 or 37° F. for King Pippin apples, though in the case of Newtown Wonders, progressively better results were obtained the lower the temperature down to 30° F., below which, of course, there is danger of injury by frost.

Apples which have been cold stored are found to be subject to troubles peculiarly their own– such, for instance, as bitter pit, black-rot, canker, scald, and brown heart. These troubles are all the subject of close investigation by scientists ; brown heart and scald have already been referred to, and it is to be hoped that the cause of the others will soon be discovered and overcome. Bitter pit is believed to be due to some action, climate, or otherwise which interferes with the normal breathing and growth of the fruit, and so causes a temporary and harmful excess of CO_2 in the interior flesh cells, producing what is really local brown heart. In New Zealand it has been found that when the normal growth of the fruit has been retarded by drought and very hot weather, and a vigorous growth, produced by rain, follows, the apples have been badly affected with bitter pit. The Food Investigation Board has arrived at the conclusion that while 33·8° F. is the correct storage temperature, below a storage temperature of about 37° F. losses are almost entirely confined to physical surroundings, and that above that temperature losses are almost wholly due to infection by moulds.

In the *Journal of Agriculture and Research* it is stated that ripe apples are less subject to bitter pit and black-rot canker than apples which are immature, and that apples from well-irrigated soils are more subject to rot than apples grown on drier soils. The Food Investigation Board states that apples grown on clay soils keep better than those grown on chalk, and those on chalk better than those on fen-land. In 1921 the Food Investigation Board carried out some tests on Newton Wonders, a variety highly susceptible to scald, and found that scald was almost entirely prevented by the use of oiled paper wrappings. They also found that gathering the fruit early tends to increase the amount of scald appearing in cold storage, and that the use of oiled paper wrappings increased the storage life of Bramley's seedlings by six weeks.

The fungoid growths, or scabs, on the skin of an apple make a most excellent breeding ground for *Penicillium Glaucum* and other moulds, and apples which have been stored in too damp an atmosphere get covered with this mould. It is, as is well known, harmless, but it renders the apple unmarketable.

Though as a general ruling it seems to be pretty well established that with a temperature of 31 to 32° F., and a humidity of 80 to 85 per cent, apples will keep better and longer than under any other conditions, it is a point to be carefully considered whether their keeping qualities cannot be

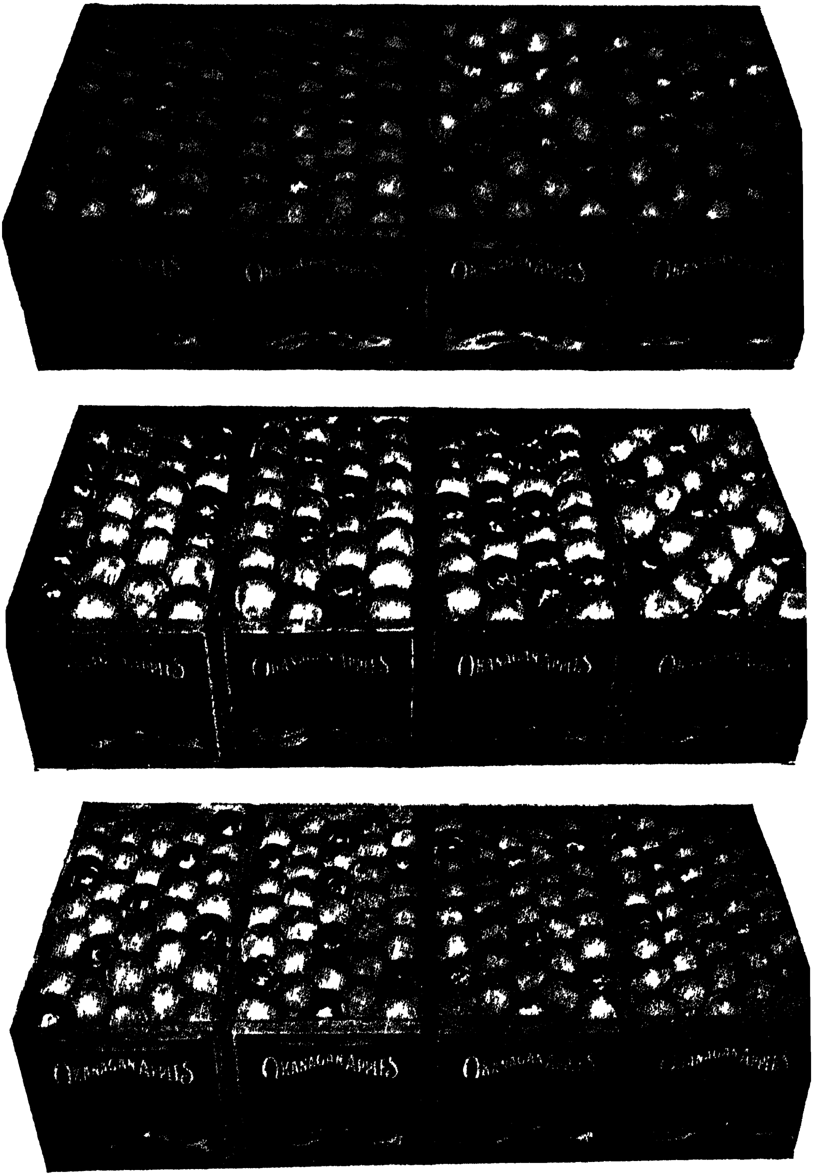

FIG. 140

improved by introducing some substance toxic to the organisms which assist decay.

It has been established by the Compagnie Internationale de Transport par le Froid, that the introduction of ozone into *the air circulating* through a fruit room has a beneficial result, not only in preserving the fruits, but in retaining the original flavour and qualities of the varieties on which the experiments were conducted.

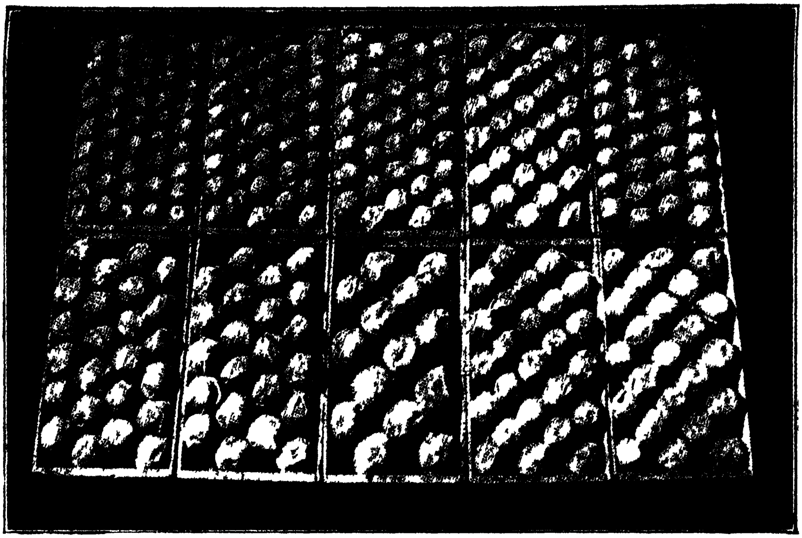

Fig 141

By the courtesy of the High Commissioner for Canada the author is able to reproduce some illustrations and text taken from that extremely interesting and invaluable publication, Bulletin No. 2 in the Fruit Commissioner's Series, and published by the Department of Agriculture, Ottawa. Fig. 140 shows different types of commercial packs. Figs. 141, 142, and 143 show other views of the packs. To quote from the Bulletin—

> **In Fig. 141 the box shown in the top left-hand corner is the 3—2—9—9 pack, 225 apples to the box, which is the smallest apple that should be packed, and is packed, on side. The next pack is the 3—2—7—8, 188 apples to the box, the largest 3—2 pack packed on side. In the middle of the top row is seen the 3—2—7—7 pack, 175 apples to the**

box, the smallest of the 3—2 packs which can be packed on end; while the next box is the 3—2—5—6 pack, 138 apples to the box, always packed on end. In the top right-hand corner is shown the smallest of the 2—2 packs, the 2—2—8—8, 128 apples to the box, packed on side, and it will be found that this pack is seldom used except for flat varieties. The pack in the bottom left-hand corner is the 2—2—6—6, 96 apples to the box, the largest 2—2 pack which packs on its side; while the next box, one size larger, is the 2—2—5—6 pack, 88 apples to the box, the smallest of the 2—2 packs packing on end. The 2—2—3—4 pack, 56 apples to the box, is illustrated in the centre of the lower row. It is a pack very seldom seen, as the apples are

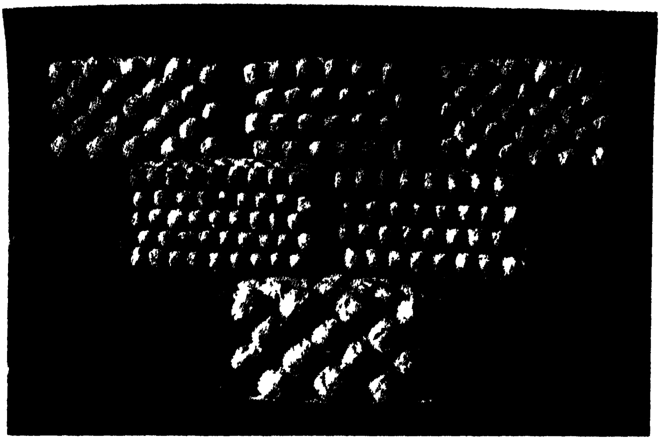

Fig. 142

Fig. 143

unusually large. It is the largest of the 2—2 packs, and packs on end. The two remaining boxes are the 3—2—4—5 and 3—2—5—5 packs, 113 and 125 apples to the box respectively. These are the two diagonal packs that have taken the place of the old 4-tier square pack which is now obsolete and should not be used.

In Fig. 142 are shown several boxes from which the covers and sides have been removed to illustrate the bulge and the construction of the pack. The three top boxes give an excellent idea as to how the bulge should look. It will also be noticed that the packs read the same from the side as from the face. This is still further illustrated in Fig. 143, where some of the same packages shown in Fig. 142 have been staged in order that the alignment may be more clearly demonstrated. The right-hand box obviously shows, from the face, that the pack is 3—2—5—6, while the side shows the same reading.

Wrapping. All apples packed in boxes, except jumble packs, should be wrapped. Wrapping is by no means a difficult operation. In fact, experienced packers can without question pack faster when wrapping the fruit.

Wrapping has several advantages—

1. It serves as a cushion, minimizing the risk of bruising.
2. It prevents rot and fungous diseases spreading from specimen to specimen.
3. It maintains a more even temperature in the fruit.
4. It gives a more finished appearance to the package when exposed for sale.
5. It preserves the freshness in appearance, and adds to the keeping qualities.
6. The paper absorbs surplus moisture.
7. It facilitates rapid packing.

Wrapping should be performed with as few movements as possible. The paper should be placed conveniently, and a rubber finger-stall worn on the middle finger of the left hand. In placing the paper, be sure to have the smooth side up. The paper is held in the left hand and the fruit to be wrapped in the right hand. The apple is then dropped or thrown into the paper on its side or end. If the pack is to be a side pack the apple is thrown into the hand on its side ; if an end pack, on its end, with the calyx to the palm. It is then wrapped with as few movements as possible and placed in the box with the left hand.

It should be remembered that every unnecessary movement will be repeated thousands of times during the day, which unnecessarily tires the packer and interferes with the speed. In this Bulletin it is not the intention to illustrate the wrap by motions. If the packer follows closely the main point at issue—namely, that he must make a neat wrap with as few movements as possible, he will attain success. Nor must it be imagined that neatness of wrap can be acquired immediately. This requires considerable practice. Probably the most important point in the actual operation is that the apple during the process of wrapping remains in the left hand until it is placed in the box, the right hand reaching for another apple. If this is followed the packer will ultimately develop a fast wrap.

The sizes of wrapping paper in common use are: 10 by 12 in. for very large apples; 10 by 10 in. for counts 56 to 96; 8 by 9 in. and 8 by 10 in. for counts 138 to 175; 8 by 8 in. for smaller apples.

Wrapping paper offers a splendid device for advertising the business of the grower or of the selling association.

There is still one more side to the question, and this could not be more clearly put than by the writers of the much quoted Bulletin No. 587—

It is not only desirable to hold apples in storage with a minimum amount of loss, but of equal importance that this fruit remain in good condition for some time after it is withdrawn and placed on the market. In many instances apples withdrawn from cold storage are reshipped for considerable distances, and in all cases they are in the hands of the wholesaler, retailer, and consumer for several days, oftentimes weeks. Allowance should be made for the length of time it will probably take a particular lot to go into consumption and the temperature and other conditions to which it will probably be subjected. As a general rule, apples should be bright, firm, and not excessively yellowed when withdrawn from storage. In some varieties deterioration in quality will limit the length of time they can safely be allowed to remain in storage. After withdrawal the fruit, of course, should be held at the lowest temperature obtainable.

It has been very generally believed that apples withdrawn from a temperature of 32° F. break down very rapidly under normal outside temperatures and deteriorate faster under these conditions than fruit which has been held at a higher temperature. The experiments show that of the two comparable lots, one from 32° F. and one from common storage, withdrawn from storage at the same time, the one from the lower temperature will hold up for a longer period in good condition. In other words, the more successfully and promptly the ripening processes of an apple are retarded the longer it will remain in good condition in and out of storage. If, however, the fruit is allowed to remain in cold storage until overripe, it will naturally break down very rapidly when withdrawn. . . . It will be seen that the amount of decay which developed during the ten-day holding period after withdrawal from storage was in nearly all cases much greater in the fruit stored at 35° F. than in that from 32° F.

Pears. In the Bulletin of the Institut Internationale du Froid for July, 1921, is a note of investigations carried out on the ripening and storage of Bartlett pears. In this the investigator, Mr. J. R. Magness, found that (1) only well developed fruit should be selected; (2) it should be placed in cold storage as soon as possible after picking; and (3) it should be cooled as rapidly as possible to 30° F., and maintained at an even temperature of 34 or 35° F. Under these conditions the fruit can be kept in storage in good condition for two to three months.

For storage, pears should be picked under-ripe, wrapped in oiled paper, and carefully packed.

The softer varieties should be stored at from 36 to 38° F., the harder kinds 3° lower. It was found at Dartford, in 1900, that Beurre d'Amanlis, Conference, Doyenne du Comice, Fertility, Pitmaston Duchess, William Bon Chretien kept well for some months. Beurre Hardy would probably have kept, but the fruit arrived in a bruised condition. William pears, as is well known, rapidly become sleepy, and keep best when picked under-ripe.

Winter Nelis is a first rate pear for storage purposes.

Peaches. Mr. W. French, the engineer in charge of the Government Fruit Cold Stores at Doncaster, Australia, gives the following information regarding the storage of peaches in a paper read before the Victorian Institution of Refrigeration.

These peaches were forwarded by growers per goods train from various districts in Victoria ; some from as far away as 200 miles inland. They were packed in nests of three trays, padded with wood wool, so that the fruits did not come in contact with one another. The fruit was well matured, but on the hard side, and, taken on the whole, arrived in very good condition. It was kept in storage for two months.

Name of Variety.	*Condition on Arrival.*	*Temperature held at*	*Humidity of Air.*	*Result.*
Elberta	Ripe and firm	31° F.	75%	Excellent
Early Crawford	Hard	,,	,,	Fair
Muir	Matured	,,	,,	Good
Late Red	Hard	,,	,,	Good
Sea Eagle	Matured	,,	,,	Fair
Pumps Seedling	Matured	,,	,,	Very good
Royal George	Hard	,,	,,	Going off
Zerber Seedling No. 1	Hard	,,	,,	Very good
Smith's	Hard	,,	,,	Good
Eitkins	Matured	,,	,,	Going off
Catherine Ann	Matured	,,	,,	Going off
Nicholl's Cling	Firm	,,	,,	Very good
Kerr's Seedlings	Hard	,,	,,	Going off
Balita	Ripe and firm	,,	,,	Good
Pullar Cling	Ripe and firm	,,	,,	Very good
Kia Ora	Firm	,,	,,	Good

Mr. French quotes another instance by way of comparison as between careful and lax methods. Several thousands of Pullar cling peaches, which were packed in old and broken cases, picked at a temperature of 120°, and were three days in transit, knocked about very badly, and stored at 31 and 32° F. The loss after a few weeks' storage was 50 per cent. The same variety, about 600 cases, picked on the firm side in the cool of the evening, packed carefully, and consigned by rail from a district forty miles inland, arrived in good condition, and after six weeks' storage at a temperature of 31 to 32° showed only 1 per cent loss.

Soft Fruits

In the United States* strawberries and other soft fruits which are popular for adding to the mix in ice cream factories, and in which it is especially desired to preserve the flavour of the fresh fruit, are preserved by packing small quantities of the fruit in airtight tins with the addition of one cup of sugar to each 10 lb. of fruit. The tins are then placed in the freezing chamber and kept until required.

In another method employed on a larger scale, not only in the U.S.A. but in England and in the continent. the raw ripe fruit is carefully washed and packed in both water and airtight barrels. with the addition of from half to one pound of sugar to each pound of fruit. The barrels are sometimes coated inside with hot paraffin applied with a paint brush to make then airtight. After the fruit and sugar have been packed in them they are hard frozen at 8 to 10° F. and kept in cold storage at a temperature of 18 to 20° F. Many thousand barrels are put up in this way each year. If a 50/50 mixture of fruit and sugar is used it can be stored at 34 to 36° F. for a short period.

In a large installation recently designed by the author for a prominent firm of jam manufacturers and orchardists in England, provision is made for keeping the fresh fruit as such for a short period to tide over the glut, and also for preserving the fruit, with sugar, in barrels for long periods, these being drawn upon for manufacture as need arises.

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* United States Department of Agriculture. Western United States Farmers' Bulletin, No. 1,027 ; G. W. Darrow.

In 1920 a number of experiments were conducted by the University of California* at the Berkeley Experimental Station, on the storage of cherries, apricots, loganberries, and strawberries. These were stored both untreated and in sugar solutions of varying density, heated and unheated, at temperatures of from 8 to 12° F.

Experiments were also made on strawberries stored at 32° F., and currants and red raspberries stored at both 8 to 12° F. and 32° F. The following is a brief *résumé* of the results obtained. The Bulletin itself should be studied for full information.

Cherries. The colour of cherries both pitted and unpitted, stored in open containers, soon became brown by oxidation. Freezing the untreated cherries in water prevented darkening of the colour during storage probably as a result of the exclusion of air. As far as retention of colour, quality, and texture of the fresh fruit was concerned, syrups varying from 10 to 40 per cent cane sugar content seemed to be no improvement over water as a storage medium, although they added somewhat to the flavour. Heating to 175° F. in water or dilute syrups before storage bleached the cherries and imparted a cooked taste. Heating to 212° F. intensified these defects. Untreated cherries stored at 32° F. soon became mouldy. Cherries stored in sulphurous acid by the usual commercial methods were inferior in flavour to those stored by the various freezing methods noted above.

Apricots. Apricots gave excellent results in several methods of storage. At 8 to 12° F. the skin of whole, untreated fruit and the skin and flesh of the halved, untreated fruit became brown. In both cases after several months' storage the fruit developed a very disagreeable " cold storage " flavour, rendering the products made from them almost inedible. The halved fruit stored in water or in syrups of 30 and 50 per cent cane sugar, retained a remarkably fresh flavour and colour, although the fruit softened noticeably on thawing. It appeared equal in all other respects to the fresh fruit. Crushed fruit with an equal weight of sugar added retained its fresh flavour and colour, and was very suitable for ice cream, short cake, etc. Very ripe fruit required only about one-half its weight of sugar to give good results. Fruit crushed and with no sugar added, became brown at the surface, but the remainder of the lot to which air had no access was of excellent fresh colour and flavour, indicating that sugar is not necessary for the retention of flavour and colour of crushed fruit.

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* Bulletin No. 324: " Storage of Perishable Fruits at Freezing Temperatures "; University of California Press, Berkeley, 1920.

Crushed fruit at 32° F. spoiled in about two weeks. Crushed fruit plus an equal weight of sugar stored at 32° F. kept perfectly. This same mixture heated to 212° F. and stored at 32° F. kept well, but possessed an "apricot preserve" flavour. The unheated fruit was preferable to the cooked article, and much superior in flavour to the ordinary canned apricot of commerce.

Loganberries. The loganberry is a very satisfactory fruit for freezing storage. It kept fairly well without treatment at 8 to 12° F. There was, however, considerable shrivelling and some loss of colour and flavour. Untreated crushed fruit kept perfectly and seemed equal to the fresh fruit in every way. Sugar added to the crushed fruit reduced its tart flavour and made the fruit richer than the unsweetened article. Heating the crushed and sweetened fruit to 165° F. and 212° F. imparted a noticeable "jam"-like flavour. Untreated fruit at 32° F. became mouldy in less than three weeks.

Red Raspberries. This fruit required less sugar than loganberries for the imparting of a rich flavour. The untreated fruit at 8 to 12° F. shrivelled slightly but retained its colour and flavour well. The crushed fruit, plus two-thirds its weight of sugar, retained more of the fresh fruit aroma and flavour than did the unsweetened fruit, but rendered it very sweet in flavour. Slightly less sugar would have been sufficient. Heating the fruit to 212° F. before storage imparted a cooked flavour.

Currants. Currants untreated at 8 to 12° F. retained their colour and flavour remarkably well and were as suitable for jelly or jam as the fresh fruit. The crushed fruit, to which was added an equal weight of sugar, retained its fresh flavour to a greater degree. Heating the crushed fruit to boiling before storage injured the quality slightly.

Strawberries. Strawberries, held untreated at 32° F., spoiled in less than six weeks; crushed and mixed with an equal weight of sugar retained their flavour, colour and aroma at 32° F. without moulding or fermenting. Heating the crushed fruit and sugar before storage injured the colour and flavour. Berries frozen in water or dilute syrups and stored at 8 to 12° F. were superior to the same fruits stored untreated. The flavour and colour of the fruit stored in water was as good as that stored in syrups. Untreated berries in open containers shrivelled slightly and lost some of their colour. Crushed unsweetened berries retained their flavour and colour very well at 8 to 12° F. The addition of sugar to the crushed berries before storage made the flavour richer, but is not necessary. Heating the crushed fruit impaired the colour and quality. Strawberries preserved by the usual household method by cooking with an equal weight of sugar and storing in sealed containers were much inferior to fruit preserved at 8 to 12° F. after similar preliminary treatment; and very much inferior to the sweetened unheated fruit stored at 8 to 12° F.

These experiments may be briefly summarized as follows—

1. Soft fruits such as apricots, cherries, and berries can be preserved at cold storage temperatures of 32° F. for not more than a week to three weeks. Present commercial methods of storing these fruits at temperatures lower than 32° F. are not standardized and are in many cases unsatisfactory.

2. These fruits if held in water or syrup at 8 to 12° F. retain their flavour and colour very well for at least a year.

3. The crushed fruits with or without sugar retained their colour and flavour almost perfectly at 8 to 12° F. for almost a year. This fruit was excellent for ice cream, for pies, for use as a jam on bread, for short cakes, and general soda fountain use.

A very extensive series of tests were also carried out on various kinds of plums. The following is summarized from the Bulletin* which should be carefully studied for full details—

TEMPERATURE OF STORAGE 32° F.

Name of Plum.	Best Storage Period, Weeks.	Marketable Period, Days.	Maximum Stor. Period, Weeks.	Marketable Period, Days.
Kelsey . .	10	9 10	14	5
Grand Duke, Tragedy, Climax .	9	8 10	12–13	5 7
Wickson . .	11 12	7–10	15 16	4–7
Satsuma . .	10 11	7 10	14	6 7
Yellow Egg, Sultan, Beauty,* Agen, Sugar.	6 7	5 8	9	3 5

* Beauty can be kept satisfactorily for nearly twelve weeks, Bulletin No. 344.

It is considered that it seldom pays to store the early varieties, as the plum season is still in full swing with later varieties, when their best period of storage has expired. The "Grand Duke" ripens late in the season and, if stored, extends the plum season and sells well. "Tragedy" and "Climax" ripen early. The report emphasizes the fact that when plums are to be shipped any distance, or stored for any length of time, it is imperative to employ the greatest care in picking, grading, packing, and handling the fruit.

Oranges. Full information on the conditions of picking, packing, and storage for oranges can be obtained from the Bulletin† issued by the Union of South Africa. It is now found that the best storage is between 38 and 40° F. If stored at a temperature much below 38° F. oranges have a peculiar flavour. The proper relation between flavour and temperature requires investigation in this as in other goods as scientifically nothing, or practically nothing, is known of it. Reference to the table on p. 373 will show that the respiration number of an orange is 1·8 compared to 4·6 for an apple, but the South African investigators have found that air circulation and ventilation are just as important in the satisfactory carrying of oranges, etc., as temperature. In fact, on some occasions when the vessels arrived at Southampton, the cool chambers were so heavily laden with gas that it was necessary to keep the stevedores from entering them for several hours after the doors had been opened. Given proper conditions, cold stored citrus fruit shows practically no waste on arrival at the end of the voyage, and is in excellent condition.

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* Bulletin No. 344: "Cold Storage as an Aid to the Marketing of Plums." University of California Press, Berkeley, 1922.

† Bulletin No. 1, 1922: Investigation on Export Citrus Fruit from South Africa during 1921; Government Printing and Stationery Office, Pretoria, 1922, 1s 6d

Nuts and Dried Fruit. The practice of cold storing these commodities is increasing. Shelled nuts should not be stored below 31° F., and 32 to 34° F. is recommended. Nuts in shell should not go below 32° F., and 34 to 35° F. is recommended, while for short periods the temperatures in both cases may be 4° higher. Cold storage is invaluable for preventing the development of grubs. The humidity should be about 75 per cent. Dried fruit is kept in storage to prevent attack by grubs, and to prevent the fruit losing weight and condition by evaporation. The humidity is very important and should be maintained at about 65 per cent.

Tomatoes. If picked just as they are beginning to redden and when still hard, wrapped in tissue paper, and carefully packed, tomatoes will keep for about two months. If picked green and stored, they will not ripen when taken out of cold storage. The fruit should have the foot stalks removed before being put into storage, as these are apt to start decay. The temperature recommended is 34 to 35° F.—humidity 75 per cent.

Grapes. These must be absolutely dry. The best results have been obtained by packing them in sawdust, but hanging the bunches in a dry atmosphere also answers well for some six or eight weeks.

If the air is too dry shrinkage will occur. The fruit must be carefully watched, and the humidity regulated by results. In the Dartford experiments it was found that Black Hamburgh and Muscats kept at a temperature of 32° for some two months; the bunches wrapped in waterproof paper came out best. The humidity is important and should be about 80 per cent. Grapes are shipped from South Africa at a temperature of 35 to 38° F.

Gas Storage of Fruit. The normal composition of the atmosphere is, of course, 79 per cent nitrogen, 21 per cent oxygen, and 0·04 per cent CO_2.

The term "gas storage" is used to denote a modified and artificially controlled condition of the atmosphere in the storage space. The idea is by no means a new one, as attempts have from time to time been made to utilize a "neutral" or "inactive" atmosphere, particularly for the storage of fruit, and on one occasion, at least, with fatal results to the experimenter.

The present developments of gas storage are due to the initiative of Sir William Hardy, F.R.S., and to the researches and experiments carried out under his direction by the Food Investigation Board in its work on the storage of apples. In these experiments, the modification to the normal atmosphere consists in increasing the proportion of CO_2 and lowering the proportion of oxygen.

The first experiments, which were carried out on a small scale at the Low Temperature Research Station, Cambridge, and elsewhere, showed such promising results that they are being continued on a large scale at the Ditton Laboratory of the East Malling Research Station, which has been specially designed and constructed for the purpose.

As has already been pointed out, apples or other living products consume oxygen and give out an approximately equal volume of CO_2. Consequently, if they are stored in a gas-tight container the proportion of the oxygen will decrease and the proportion of CO_2 will increase. The sum of the volumes of these two gases remains constant at 21 per cent of the atmosphere, the balance being, of course, the nitrogen, which is unaffected.

This results in slowing down the respiratory activity of the apple, and therefore, in extending its storage period, but the method has its limits, because too great an accumulation of CO_2 results in asphyxiation and the development of brown heart. Furthermore, unless refrigeration is employed to control the temperature, the heat generated in a large bulk of fruit cannot be dissipated, and raises the temperature of the mass to such an extent that the increased respiratory activity due to the increase in temperature nullifies the retarding effect caused by the modification of the atmosphere.

There is a critical temperature for every variety of apple. This is generally somewhat above the freezing point of its tissue. Below this point the normal metabolism is unbalanced, leading to low temperature breakdown and to a rapid decay of the fruit after it has been removed from storage to ordinary temperatures.

With Newton Wonder apples this critical temperature is nearly 32° F. With Bramley's Seedling it is 37° F., and with King Pippins it is 38° F. There is in general terms an increase in the length of storage life as the temperature falls to these figures, and a decreasing storage life as the temperature falls below them.

The commercial storage life of apples is taken as that time in which the wastage during storage has not exceeded 10 per cent of the bulk. Experiments carried out by the Food Investigation Board over a number of years with Bramley's Seedling apples in a normal atmosphere at 34° F. has shown that this wastage has occurred before the end of February. It would, of course, have been possible to prolong the storage period if a temperature nearer the critical point had been employed, but at this temperature the ripening would have been so accelerated that the post-storage life of the apple would have been greatly reduced.

The development of gas storage in conjunction with refrigeration has resulted from an endeavour to extend the commercial storage period without the liability of this rapid breakdown on marketing after storage.

It has been proved that in an atmosphere containing a moderate proportion of CO_2 the best results are obtained when the temperature is maintained slightly above the critical temperature. The fruit then remains sound for a long period after storage. A further advantage of gas storage for ordinary varieties of apples is that the CO_2 has a marked effect in slowing down the normal change of colour from green to yellow.

For Bramley's Seedling apples an average storage temperature of 40° F., with an atmosphere containing 10 per cent of carbon dioxide and 11 per cent oxygen, is recommended. The same conditions apply for Lane's Prince Albert apples. Further extended experiments are required to co-relate the effects of temperature and the concentration of CO_2 before definite recommendations can be made with regard to the storage of other varieties of apples. The tests so far completed show that, with practically all varieties, an appropriate gas concentration and temperature will give superior results to cold storage in ordinary air.

At the Ditton Laboratory a large store has been constructed, measuring 30 ft. 6 in. by 34 ft. 6 in. by 15 ft. inside dimensions. and capable of taking 120 tons of fruit. This has a steel shell outside the insulation to enable it to be kept as nearly as possible airtight, and to reproduce the conditions of a ship's hold. The store itself is contained in an insulated space, so that the temperature immediately outside it can be controlled at will. There are also a series of thirty small gastight cabinets arranged in three rooms, which are maintained at constant temperatures of 1° C., 4° C., and 10° C., and ten different conditions of gas concentration can be used at each of the three temperatures.

It has been ascertained at Ditton that the production of CO_2 from fruit in an ordinary atmosphere at about 37° F. is at the rate of approximately 1·45 cu. ft. per day per ton of fruit in store. With gas storage it is estimated that the volume of CO_2 generated is reduced to about half this figure.

With commercial gas storage of fruit an absence of ventilation will quickly provide a concentration of CO_2 owing to the generation of the gas by the fruit. Owing, however, to the porous nature of insulating and building materials, and the great difficulty in getting anything like an airtight construction, it is necessary to take special measures to maintain the desired degree of concentration

§ 7. Hops

The proper temperature for hops is 28° F. When first harvested they are dried in kilns, packed and sent to market. During the drying process some of the essential oils are driven off and, if subsequently stored at ordinary temperatures, this process goes slowly on until the hops lose the peculiar aroma and flavour which constitutes their value and which is given them by these oils. The drying process is essential, otherwise the hops would become crusted and useless ; but it has been found that keeping them in cold storage retards the subsequent volatilization of the oil and retains their quality. The proper temperature for storage is 28° F., though many store at 32 to 34° F. The storage rooms should be constructed in the ordinary manner, and cooling may be done by either of the three systems ; air circulation is frequently employed. There is no occasion for the rooms to be ventilated and the same air can be circulated over and over again. The humidity should be kept at about 70, and the rooms should be perfectly dark. Great care must be taken in keeping the rooms absolutely dry, as the hops will be ruined if allowed to get moist.

Hops must also be carefully treated when brought out of cold storage to prevent moisture depositing upon them. There is no need, systematically, to defrost them by process ; all they require is to be gradually tempered up to the temperature of the outside air.

Needless to say, cold air that has been in contact with hops must not be allowed to come in contact with other goods.

§ 8. Meat

Frozen. Proper temperature 14° F. Most of the cold stores in England, used for the storage of frozen meat, are cooled to a temperature of about 17° F. to 18° F.

The researches of the Food Investigation Board have shown that a temperature of 17° F. is necessary to inhibit the growth of moulds.

The best conditions for storage are obtained when the temperature is definitely below 17° F., and 14° F. is recommended.

It is also recommended that the stores for frozen meat should be cooled by direct expansion or by brine piping, as with these systems, there is less loss of weight than there is in stores cooled by air circulation with "wet battery" air coolers. Meat when frozen is one of the simplest things to cold store. It is one of the few animal substances which does not gas, and it will keep for long periods without the air being changed. As a general rule the carcases are packed one on top of the other just as they come into the store, and their irregular shape allows the air to circulate round them and reach every portion. Meat will *keep* for an indefinite period, but if stored too long becomes stale, goes off colour, and deteriorates in value as a marketable commodity. (*See* notes on "Black Spot," pp. 361–363.) It is also desirable to subject it as little as possible to changes of temperature.

For short periods of storage (a week or ten days), as in distributing depots, it is better to keep the meat at a temperature of 22 to 25° F. This reduces sweating when the meat is removed for sale, and also shortens the thawing period in the butchers' shops.

Chilled. Proper temperature 29° F. Chilled meat will not keep for long periods, twenty-eight days being about the limit. This is sufficient to enable it to be brought from the River Plate to England and sold. Chilled meat has in all cases to be hung like fresh meat, and a variation of a degree one way or the other is bad.

The sterilizing system invented by Mr. J. A. Linley has been employed both in the Argentine and Australian trade. It consists essentially of vaporizing formaldehyde and driving it through the holds, thus sterilizing both the holds and the meat contained in them. Shipments of chilled meat preserved by this method were sent from the Redbank Works, Brisbane, in 1909, 1910, and 1911. The passage occupied sixty-two days, and the meat arrived in excellent condition.*

Unfortunately the formaldehyde penetrates into the tissues, and as it is considered to be harmful to man, a Government committee decided, prior to the Public Health Regulations referred to at the beginning of the chapter, that it must not under any conditions be used as a preservative for meat or any other foodstuff.

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* For further particulars see *History of the Frozen Meat Trade*, by Critchell and Raymond; Constable & Co., Ltd., London.

A relatively large consignment of chilled beef was brought from Brisbane on the s.s. "Port Darwin," and arrived in good condition after a voyage of 63 days, without the aid of any chemical preservatives.

This experimental shipment is of particular interest because the principle involved is the storage of the meat in a well ventilated chamber, through which a circulation of relatively dry air is maintained. As a result, the surface of the meat is dried, so that not only are the conditions for the growth of mould and bacteria unfavourable, but the dried surface forms a mechanical barrier against the invasion of these micro organisms.

The tissues of a healthy animal are sterile, or practically so, and the length of time that meat can be successfully stored depends, therefore, in a large measure on the conditions in the slaughterhouse.

The conditions of an operating theatre obviously cannot be applied in a meat works, but nevertheless, the conditions there should be as aseptic as possible, and the processes should be completed rapidly so as to reduce, as far as practicable, the time for the development of bacteria while the meat is warm and things are favourable for them.

Following the success obtained with the gas storage of apples, Dr. T. Moran, of the Food Investigation Board, carried out a number of exhaustive experiments on the storage of beef in atmospheres containing various degrees of concentration of carbon dioxide. He found that these resulted in a very marked retardation of the time required for the development of moulds on meat.

It appears that practically complete inhibition of growth can be obtained by concentrations approximating 50 per cent CO_2, but with these the meat turns brown and the fat is bleached after a short period. To avoid any effect upon the appearance or palatability of the meat the concentration of CO_2 should not exceed 30 per cent.

With lean meat a concentration of 10 per cent slows down the growth of mould in the early stages to one-half, while 20 per cent of CO_2 effects complete inhibition for all practical purposes. This also applies to the growth of mould on fat and ordinary tissues, though not quite to such a marked extent.

The experiments indicated that an atmosphere containing from 10 per cent to 20 per cent of CO_2 might be employed in the shipment of chilled beef from Australia and New Zealand, regions which were outside the range of the method then used in the Argentine trade.

On shipboard there is no serious difficulty in maintaining this concentration, and after discharge from the ship's hold, the meat of course goes through the same process of marketing as the Argentine beef. The trade has in fact become established and regular shipments are made from both Dominions.

It is very doubtful, however, whether, owing to physical difficulties of construction, the method used would be practicable in any commercial cold store on land, certainly in any cold store constructed on existing lines.

CHAPTER XIII

OTHER APPLICATIONS

§1. Air Cooling

OUR atmosphere, of course, consists of a mixture of air and water vapour. There is nearly always present a small percentage of CO_2 and, particularly in manufacturing districts, traces of other impurities, but these can be excluded in any consideration of air cooling.

In a mixture of gases the total pressure is the sum of the pressures of each, and the partial pressure exerted by each gas is in direct proportion to its volume. Thus, in 1 cu. ft. at atmospheric pressure of 14·7 lb. per sq. in. absolute and occupied by equal parts of two gases, each of these independently exerts a pressure of 7·35 lb. per sq. in. absolute.

In a mixture of gas and vapour such as the air, the quantity of the vapour depends upon its physical characteristics, and is limited by its saturation pressures and temperatures. At a temperature of 65° F. the pressure of water vapour is 0·617 in. of mercury, and 1 cu. ft. weighs 6·81 grains. It is at that temperature impossible for water vapour to sustain a greater pressure. If it were applied partial condensation would result, and the pressure actually remain constant. Similarly, with a reduction in temperature there would be condensation owing to the reduction of pressure which the vapour can sustain.

When the vapour content of air is at its maximum for any particular temperature, the air is said to be saturated, or to have 100 per cent humidity.

Taking saturated air at a temperature of 65° F. and a pressure of 30 in. of mercury, the pressure due to the vapour is therefore 0·617 in., and the balance of 29·383 in. is the pressure due to the air.

At a pressure of 29·383 in., 1 cu. ft. of air weighs about 520·27 grains, so that the weight of saturated air at 65° F. is about 527·08 grains per cu. ft. If this cubic-foot of air is cooled to 35° F., with the pressure remaining constant at 30 in., the total weight will, of course, remain the same, but the volume will be reduced in accordance with the laws of gases to about 0·94 cu. ft. The vapour pressure corresponding to 35° F. is 0·204 in., and at that pressure and temperature 1 cu. ft. of vapour weighs 2·39 grains. In 0·94 cu. ft. there would therefore be about 2·25 grains, and in the process of cooling from 65 to 35° F., 4·56 grains of water vapour are condensed from 1 cu. ft. of air measured at the initial temperature.

In any problem involving the cooling of quantities of air, this question of condensation of water must be investigated as, in order to effect the condensation, the latent heat must be extracted by the refrigerating plant. If the cooler is of the dry pipe type and the final temperatures are below freezing point, the latent heat of freezing of the condensed vapour must also be included.

The latent heat of condensation of water vapour is about 1,050 B.T.U. per lb., and the specific heat of air is about 0·238, so that—excluding small corrections for the cooling of the condensed liquid and higher specific heat of the small proportion of water vapour—the refrigerating power to cool 1,000 cu. ft. of saturated air from 65 to 35° F., and at 30 in. pressure, is—

For cooling dry air $\frac{1000 \times 527{\cdot}08}{7000} = 75{\cdot}3$ lb. × 30° F × 0·238 = 537·5 B.T.U.

For condensing vapour $\frac{1000 \times 4{\cdot}56}{7000} = 0{\cdot}65$ lb. × 1050 = 682·5 B.T.U.

Total . . . . . . 1220·0 B.T.U.

It is seldom that air in its normal state is completely saturated, and a rough approximation of the refrigeration power required for air cooling under the average conditions that are met with can be obtained by doubling the power required to cool the air considered as dry air only.

Whatever, originally, the humidity of the air may be, there arrives a point, when it is being cooled, at which the saturated state occurs and further cooling involves condensation. That point in relation to the initial temperature conditions, is referred to as the " dew " point.

The degree of saturation of the air can be determined by comparison of simultaneous readings of the dry and of the wet bulb thermometers, and the various conditions are fully set out in Glaisher's tables.

The temperature at which work can be efficiently carried out is largely dependent on the evaporative capacity of the air, and this is governed to a greater extent by its humidity than its actual dry bulb temperature. A man can work quite well in a temperature of 120° F. provided that the wet bulb reading is low, but with a wet bulb reading of over 80° F. the work becomes exceedingly difficult, and at 90° F. almost impossible. This condition was reached in the Morro Vehlo mine of the St. John Del Rey Mining Co. in Brazil, which is of exceptional depth, the workings extending to 6,400 ft. below the surface level. After full consideration of all the factors, a refrigerating plant with a capacity of about 6,000,000 B.T.U. per hour was installed to cool the whole of the 80,000 cu. ft. of air, per minute, used for ventilating the mine to a temperature at the surface where the coolers were installed of about 43° F. The result of this was a very marked improvement in the conditions of the mine and the health of the men. The output increased, there was a reduction in the number of accidents, and the refrigerating plant was completely justified.

A number of very large installations have been put down in England, in the United States, and in Germany to cool the air supply to blast furnaces in order to dry it and obtain a constant working condition. Experience with these plants in England, however, has shown that atmospheric conditions do not vary sufficiently to make the installation of this type of plant an economic proposition.

On a smaller scale refrigerating machinery is used for cooling and conditioning the air in hotels and assembly rooms. At least one example has been reported from the United States of such a plant in a church.

Its use in chocolate factories is referred to in detail in § 3, and it is employed in chemical works where, for special purposes, dry air and a constant and controlled condition are required in any particular room or rooms.

§ 2. Brewery Refrigeration

In considering the objects of refrigeration in a brewery it is necessary to make a clear distinction between breweries for ales, that are almost universal in England, and the breweries for lager beer that are general on the Continent and, up to the advent of prohibition, in the United States. In both types it is necessary to control the temperatures throughout the process, and from the refrigerating point of view the difference is largely one of degree.

In the brewing of ales it is seldom necessary to reduce temperatures below 55 or 60° F., so that the necessary control can be obtained by means of well water at 50 to 55° F., and ordinary cellars provide sufficiently cooled storage space. As, however, sufficiently cold well water is very seldom available or, if available, is frequently insufficient in quantity, the refrigerating machine is called in to deputise for it, and as it enables the water used for cooling to be obtained at a rather lower temperature than the well supply, it gives a far better control over the processes of cooling.

In the brewing of lager beers refrigeration is essential from first to last, and while, in England, the refrigerating machine was in the first case largely developed in connection with the meat trade, in Germany its early application was almost entirely for breweries.

The main objects of placing the refrigerating machine in a brewery are—

1. Readily to cool the wort after it comes from the coppers and before it is pitched with yeast for fermenting, and
2. To cool liquor for attemperating the wort during fermentation.

With lager beers the fermenting and storage rooms have to be cooled and there are other purposes, such as the storage of hops and of yeast, and in the quick chilling process for bright, non-deposit beers.

A refrigerating machine as used in a brewery is practically the same as that used for any other purpose ; the only difference is in the application, and before this can be studied it is necessary to know something of the nature of the wort to be cooled, and also of what goes on in the vats during fermentation, or, as it is sometimes called, attenuation.

The Cooling of Wort. Wort is the liquid resulting from the mashing of malt and the boiling of the extract with hops. It is rich in nitrogenous matter, and therefore readily becomes acid or putrid if allowed to stand after it has been boiled. For this reason it should, as it comes from the hopback, be at once cooled and impregnated with pitching yeast of vigorous growth, specially cultivated for the purpose. It is desirable to cool wort in contact with air, as at high temperatures it will take oxygen into combination, and by that means throw off matter held in solution. It is in consequence of this property that aerated wort will eventually become bright and clear, a result unattainable when air has been excluded during cooling. Some brewers pass the wort, as it comes from the hopbacks, directly over the refrigerator, first giving it a slight fall in order to aerate it ; this method, however, requires large refrigerating power, and the more usual course is to pump it first over the cooler—which consists of shallow vessels, sometimes of wood, but preferably of flush-riveted copper—where it loses some of its heat by radiation, and so does not make such a large demand on the refrigerating machine. A further function of the cooler is to permit the deposit of the coagulated protein matters from the wort and to leave the bulk of this behind when it is run down over the refrigerator.

At temperatures of 145° or 150° and upwards wort is practically sterile, and though at lower temperatures it is not a particularly favourable medium for bacterial development, it is nevertheless susceptible to bacterial infection or the development of wild yeasts which may very easily make the beer absolutely undrinkable. It is necessary, therefore, that the wort should be protected from infection during the process of cooling, and that the cooling in itself should be carried out as rapidly as possible. Primarily, of course, the cooler must be kept perfectly clean in order that infection may not arise from matter left on it, and it is now general practice to enclose the cooler in an airtight room, ventilated by filtered and purified air, to eliminate the risk of air-borne infection, which may either be of bacterial nature or, during the spring and summer months, in the form of wild yeasts which form on the outside surfaces of fruit.

The refrigerator is supplied with refrigerated or iced liquor cooled to a temperature of from 40 to 50° F., or, where liquor is scarce and has to be bought from the water companies, to a temperature as low as 33° F. In the rapid cooling over these refrigerators the wort deposits the matter previously held in solution, and this matter is left adhering to the cooler. The temperature of the wort as it leaves the cooler is, with pale ale, from 55 to 60° F., and at this temperature. or whatever is normal to the system in use, it runs off to the fermenting vats, where, as before stated, it is at once pitched with yeast.

The Fermentation of Wort. In fermentation the action which takes place is much more complex ; in fact—though that is hardly a question to be gone into here—it was not understood by brewers themselves until Pasteur developed and proved the theory that fermentation was due to the development of the microbes or cell life of which the deposit in wort and beer largely consists. Before pointing out the action of fermentation, however, it will be necessary to go back slightly and inquire what causes it. During the conversion of barley into malt, a substance is formed which is known as " diastase " ; this converts the insoluble starch of the barley into a soluble and fermentable sugar, and this sugar, when absorbed as oxygen by the yeast, splits up into nearly equal proportions of CO_2 and alcohol. The true yeast microbe is a special form of cell, whose normal condition of existence is one removed from the air—i.e. anaërobic : it feeds on the nitrogenous matter present in the wort, and breathes the combined oxygen of the sugar of the malt, splitting it up as described. The *fermentable body,* therefore, is the one capable of giving up its oxygen, and the *ferment* is the microbe having the power of taking it. Under the action of this microbe the excess of nitrogenous matter is absorbed, fermentability is decreased by the transformation of the sugar, and the beer is made stable by the addition of the alcohol in an active form which was previously present in a passive one. This action of fermentation is accompanied by heat, and the rise in temperature varies with the character of the beer and the system of fermentation in use, the ordinary rule for English breweries being a rise of about 1° F. per pound of gravity. The temperature at which it is necessary to keep the wort is easily found when it is remembered that it is not considered safe or desirable to exceed, at any rate for pale ale, the limit of 70° F. The brewer with this class of ale, therefore, would start at a temperature of, say, 58 or 59° F., and would gradually rise, attaining a temperature of 68 or 69° F. by the time fermentation was complete. With strong beers containing a large quantity of malt, and in which the rise per pound is higher, fermentation is started at a lower temperature, in order that the final temperature may not exceed the limit of 70° F. Of course, with very strong beers containing an excess of alcohol this limit of 70° F. may be exceeded without danger, as, owing to the presence of the alcohol, its stability is greater. After fermentation the beer is usually held at the same temperature for about five hours; it is then gradually thrown back at the rate, at first, of a degree in five hours, then another degree in, say, four hours, the rate getting quicker and quicker until the racking temperature is reached.

It may be remarked in passing that the speed of fermentation, which, however, is more a matter for the brewer than the engineer, has a distinct bearing upon the character of the beer. High temperatures are said to give a peculiar flavour which is much sought after, but rapid attenuation—and, consequently, a high temperature—is liable to cause difficulties in clarification and a lowness of stability owing to the formation of weak alcohols.

Heat to be Removed. The exact quantity of heat to be removed from the wort during cooling varies with its sensible and specific heat and its specific gravity. Ale wort, as brewed in England, is not cooled below a temperature of from about 60 to 55° F., and the storage rooms are not kept much below the same temperature. With lager and other weak beers, on the other hand, much lower temperatures are necessary.

The heat to be removed during fermentation varies with the specific gravity of the wort, or, in other words, with the amount of malt or saccharine matter that has been used in its manufacture, and much more refrigeration is required for strong beers containing much malt than for weak beers containing little. These quantities are easily calculated from well-established formulae for various strengths of beer, and the size of the refrigerating machine installed depends on the result. The wort, however, has to be cooled very rapidly, and, therefore, a large quantity of heat has to be removed in a very short time; this is the most important factor in determining the size of the machine. The refrigerating capacity required for cooling yeast rooms, cellars, etc., is ascertainable on ordinary cold storage rules, and presents no special features or difficulties; but it must be remembered, in this connection, that fermentation is not usually completed in the fermenting vats, and that the beer still continues to give off heat when it is standing in casks in the cellars.

The specific heat of wort decreases as the specific gravity rises. This latter is usually ascertained among English brewers by the "pounds per barrel" saccharometer, and as specific gravity shows how much heavier or lighter a liquid is than water which is taken as 1,000, so saccharometer pounds show the weight of a barrel of wort in excess of that of a barrel of water which weighs 360 lb. There are several saccharometers in use, each having its own table of constants; as a rule, they are correct at 60° F., and a constant figure has to be added for every degree the wort is in excess of that temperature. The average brew of ale wort will show 19·8 on the pounds per barrel saccharometer corresponding to a specific gravity of 1,055, which is the excise standard, and to a specific heat of about ·905; during fermentation it will lose about 40, and when ready for racking will show about 1,015 (5·4 lb. per barrel). Stout will probably show 1,090 (32·4 lb. per barrel), and will be brought down to 1,035 (12·6 lb. per barrel).

During the Cooling of the Wort. The wort loses a certain amount of heat by radiation in the hopback and the pipes through which it passes to the cooling floor, so that by the time it reaches the refrigerator its temperature is about 140° F. Sometimes, however. it is passed from the hopback directly on to the refrigerators; in this case it reaches them at a temperature of about 190° F., and, if pale ale, is reduced by them to a temperature of from 55 to 60° F. The general arrangement of the refrigerators will be described more fully subsequently. For the present it is sufficient to say that they are generally made in two portions. The upper coils are supplied with well or water companies' liquor or water, which forecools the wort and reduces its temperature to about 70° F., and the lower coils with iced liquor, refrigerated brine, or (more rarely in England) by directly expanded ammonia, which further reduces the temperature. The term iced liquor is a survival of the days prior to the introduction of mechanical refrigeration, when ice used to be bought and put into the cold liquor back or tank to reduce the temperature of the cooling liquor. The term has survived, though the methods have changed. Where liquor is scarce it is sometimes reduced to a temperature of from 33 to 34° F., and fed through all the coils of the refrigerator, entering at the bottom and leaving at the top. In any case the total heat to be removed from the wort is the same, and, having ascertained the average strength of the wort brewed, and, therefore, its specific weight or gravity and heat, the number of British thermal units to be removed would be—

$$\text{B.T.U.} = B \times 360 \times g \times s\,(t - 40),^{*}$$

in which B = number of barrels to be cooled; 360 = the number of pounds in a barrel (36 × 10); g = the specific gravity of the wort; s = the corresponding specific heat; and t = the temperature to which the wort is cooled by the upper coils which are fed with well or water companies' (unrefrigerated) liquor.

If it is required to reduce the British thermal units to tons refrigeration, the product of the above formula must be divided by 288,000, but it must not be overlooked that the rating in tons refrigeration is taken with ammonia evaporating at 5° F., and that the refrigerating machine in a brewery will, in all probability, be working with a very much higher evaporator temperature and, consequently, with a much greater thermal abstraction for a given compressor size.

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* Siebel; adapted for British units.

The essence of the successful cooling of wort is rapidity, and, therefore, the actual size of the machine capable of doing this must be considerably greater than the above results would suggest. The rate at which a given quantity of wort can be cooled is obviously governed by the number and size of the refrigerators available, each refrigerator only being capable of efficiently passing a certain quantity of wort in a given time. To find the actual size of the machine required for wort cooling, therefore, the tonnage given above must be multiplied by 24 divided by the time in hours which the refrigerator takes to pass the wort.

As the wort cooling only occupies a relatively short period it would, therefore, call for a powerful refrigerating machine limited to that period of working only. It is general practice to deliver the cooled water up to a large storage tank, so that the accumulated refrigerating effect of several hours working can be utilized during the short period that the wort is being cooled.

During the Fermentation of the Wort. After fermentation there is a slight decrease in the quantity of the wort, due to the consumption of the yeast-forming matter; it is not great, however, and hardly affects the total. The heat generated by 1 lb. of maltose while splitting up under the action of the yeast into alcohol and CO_2 is approximately 330 B.T.U. In order to find accurately the heat in B.T.U., H to be removed by the attemperators during fermentation, the specific gravities of the wort (b) and of the beer (b_1) must be found. The following formula can then be used—

$$H = \frac{B \times 0{\cdot}91\,(b - b_1)\,(360 \times b)\,330}{100},^{*}$$

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* Siebel; adapted for British units.

or, if in tons refrigeration, the product must be divided as before by 288,000.

As, however, the specific heat of wort is so near that of water, it is sufficient for preliminary estimates to let

$$H = B \times 360 \times 330 \text{ B.T.U.}$$

As the amount of saccharine matter in the beer becomes less, the heat to be withdrawn during fermentation decreases, and the smaller will be the refrigerators required.

Other Duties of the Refrigerating Machine. The remaining duties to be performed by the refrigerating machine are the cooling of the cellars, yeast rooms, hop stores, etc. It is quite impossible to lay down any formulae for this work, as the refrigeration required depends on so many factors, which in practice have a constantly varying value. The most important factor is, of course, the insulation of the walls of the cellars and rooms, but the frequency with which they are entered and the temperature of the beer stored have also to be considered. Cellars are usually kept cool by piping as opposed to air blast, and the amount of piping required depends on the above factors, and, in addition, on the initial temperature of the medium circulated through them. It is, therefore, absolutely necessary, in dealing with these particular items, to take each case on its own merits, and to lay down no general rules, which will only mislead and cause loss and trouble.

For instance, American writers have stated that as a rough figure the refrigeration tonnage required in a brewery may be obtained by dividing the number of barrels brewed per day by 4, and that in cooling wort one ton of refrigeration is required for 40 barrels, while for removing the heat of fermentation one ton is required for 35 barrels. These are not set out as accurate or reliable rules, but the danger of accepting them, even approximately, for British practice will be realized when it is remembered that in the United States a barrel is 31 gallons of 8·3 lb., a ton refrigeration represents 288,000 B.T.U., and that lager beer was produced in practically all the American breweries.

Types of Wort Coolers. The various types of wort refrigerators, both vertical and horizontal, used in breweries are well known and need not be described. The Baudelot cooler, pure and simple, has now largely gone out of use for this purpose, its place being taken by refrigerators with flattened pipes, giving a better interchange of heat.

The horizontal cooler is not often used alone, but frequently in combination with a vertical one. In this case it is usual to arrange them in the form of the letter **L.** The hot wort flows down the vertical part of the cooler, where it is aerated, and then over the corrugations of the horizontal portion. The cooling liquor pursues the opposite course, entering the horizontal portion at the bottom, and—if the temperature range is great enough to stand it—leaving the vertical portion at the top. The warm liquor thus meets the hot wort. Usually, however, the vertical portion is supplied entirely with well water at a temperature of about 60° F. or whatever it may be, and the horizontal portion with iced liquor at a temperature of about 40° F. or lower, as the case may be. Where only vertical refrigerators are used, as is the case in perhaps the majority of breweries, either the whole refrigerator is supplied with iced liquor, or the upper tubes are supplied with well liquor and the lower ten tubes or thereabouts with iced liquor.

The Direct Expansion Wort Cooler. For lager beer lower temperatures all round are carried. The storage cellars are sometimes kept at 32° F. and the fermenting rooms at 36° F. It is now common practice, in view of these low temperatures, to use well liquor in the upper coils of the refrigerator, and to cool the lower coils either by the circulation of cold brine or by expanding ammonia directly through them as shown in Fig. 144. The average English brewer would, and does, consider this dangerous, but it is really not so, as there is practically no chance of an escape of brine or of ammonia gas into the wort. As ammonia attacks copper, this material cannot be used in the refrigerator, therefore the lower coils have to be of iron or steel. In order to conform to custom and to prevent rusting, the practice at first was to cover these steel pipes with a thin sheet of copper drawn on over the iron pipe. In some cases, however, it was found that, owing to imperfect work, an air space formed between the iron pipe

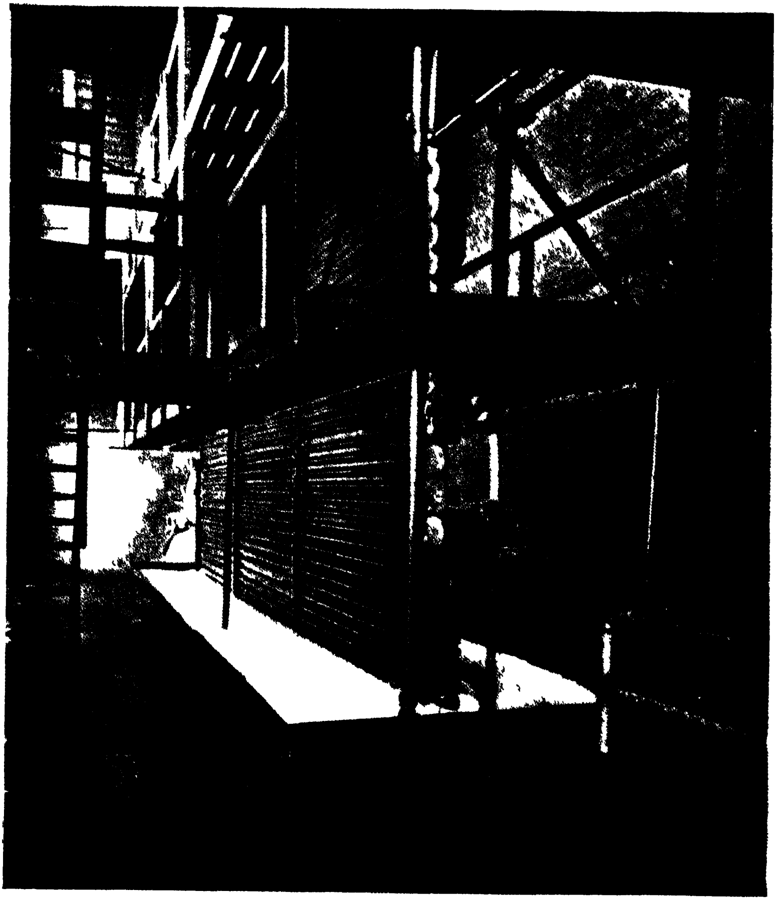

FIG. 144

and its copper covering, preventing a proper interchange of heat, and thus reducing the efficiency of the apparatus. As a result, and after experiment, the copper covering has been discarded altogether, the iron or steel pipes being ground bright, polished, and used direct. The action of the wort running over the cooler produces a skin on the iron which acts like a varnish, and, as it does not deteriorate, effectively prevents any tendency to rust. In fact, so far as this matter is concerned, there is no reason why the whole cooler should not be made of bright iron or steel tubes.

There is, however, a practical objection to cooling by direct expansion. Very few ale breweries require or have separate machines or compressors for wort cooling only, the usual arrangement being the installation of one or two machines for all purposes. Now, as wort cooling represents about three-fourths of the total refrigerating work required, and, moreover, has to be done in a very short time, it is necessary perhaps to turn the whole refrigerating capacity of the brewery on to it, leaving the cellars, etc., to look after themselves for the time. As the wort does not usually require to be cooled to a very low temperature, the temperature of the expanding ammonia in the lower coils need not be lower than, say, 30 to 35° F., corresponding to a gauge back pressure of from 45 to 51 lb. per sq. in. the temperature depending on the strength of the ale brewed : and, as it is a direct gain to have the back pressure as high as possible, this is an economical advantage. The cellars, however, and more particularly the liquor coolers, are probably being run at a lower temperature, and, therefore, the gas returning to the refrigerating machine from the expansion pipes in them is at a lower pressure than that coming from the wort cooler. This introduces difficulties which are not easy to overcome, and if, as before stated, the whole power of the machine is put on to wort cooling for the short time it is in progress, the other portions of the brewery requiring refrigeration are left without it, and the temperatures begin to rise.

It has as a result been found advisable, where this class of wort cooler is employed, either to connect the front and back ends of the compressor separately, and work them at different back pressures with direct expansion everywhere, or to use brine circulation in the cellars and yeast rooms. Though this latter method, by introducing an extra interchange of heat, is not directly so efficient as the direct expansion system, it is much more easy to manipulate. The cooled brine is stored in a tank, and is then pumped from it through the pipes in the cellars. A reserve of cold brine is thus produced, so that when the whole refrigerating capacity is put on to wort cooling, the brine pump can still circulate sufficient cold brine drawn from the tank to keep the rest of the work going.

As the ammonia is expanded directly into the coils of the wort coolers, the ammonia gas returning to the compressor is all of the same pressure ; the machine is working at its highest efficiency, and no difficulty arises. The expansion valve or valves by the coolers will have, however, to be carefully regulated, especially when top feed is in use, or the liquid ammonia will be freezing back to the compressor, and giving trouble in that way. When brine is used, the temperature in any particular room or place can be varied at will by the use of valves which control its circulation through the pipes. Brine has also been used in this way for wort cooling instead of the direct expansion of ammonia. In this case about 20 per cent more cooling surface has to be allowed, but the whole of the cooler may be of copper pipe.

Attemporators. The heat of fermentation is removed by the attemporator, which is a coil of tinned copper pipe, usually of a flattened section, placed in the fermenting vat. Through this coil of pipe, the length of which varies according to the strength of the beer, iced liquor is circulated, taking up the heat. Sometimes refrigerated brine is used for this purpose as well, but sweet iced liquor is almost invariably preferred, especially where the attemporators are of the swivel removable type, as being on the whole better for the purpose. This liquor is cooled in a submerged cooler, or by letting it flow over the coils of a Baudelot cooler in which ammonia is expanding or brine circulating ; it is then pumped to a tank placed at a higher level than the fermenting vats, and allowed to flow by gravity through the coils of the attemporators, the exact amount passing, and so the temperature being regulated as desired, by valves placed against each vat. Sometimes the fermenting tuns are covered in and brine coils are arranged inside the top of the covering.

Submerged and Baudelot Coolers. Carbonic anhydride being a natural product of the brewery, it is only to be expected that brewers would, other things being equal, favour any machine using this gas as a refrigerating agent on account of the harmlessness of any escape which might occur; and, acting probably on this reasoning, a large number of CO_2 machines have been installed in breweries. So far as the duties to be performed by the refrigerating machine are concerned, it is a matter of indifference whether ammonia or CO_2 is employed as the refrigerating agent, and the methods used in distributing the refrigeration produced by a CO_2 machine do not differ materially from those already described. When cellars or hop stores are to be cooled, the expanding CO_2 cools brine, which is circulated in pipes, or, if air circulation is desired, the ordinary brine air battery is used.

With CO_2 refrigerating machinery liquor coolers of both the submerged and Baudelot type are employed. The submerged cooler is, generally, of similar construction to the submerged condenser, and consists of an insulated tank, in which the evaporating coils are placed and surrounded by the liquor to be cooled. The manifolds of the coils protrude at the top and bottom of the cooler, and the ends of the coils pass through glands in the casing, so that none of the joints are submerged or out of sight. It is considered by some authorities that the submerged cooler is more efficient than the Baudelot type, because in the latter there is a loss due to the warm air which comes in contact with the cold pipes and cooled liquor being chilled, and thus uselessly absorbing some of the power of the machine. This, however, will not occur if the coolers are, as they should be, enclosed in an insulated chamber.

On the other hand, it is urged by the advocates of the Baudelot cooler that as an elementary law of the transmission of heat states that the rate of transmission of heat from a cold surface to water increases in a direct proportion to the rate at which the water passes over that surface, submerged coolers can hardly be as efficient as the Baudelot type, on account of the more sluggish circulation of the liquor to be cooled. They also urge the further objection that, if the temperature is at all low, ice is liable to form on the expansion coils, which is, of course, all against the machine. This latter eventuality may, and does, happen with the open type cooler ; but, owing to the greater velocity with which the liquor passes over the coils, lower temperatures may be reached before the ice begins to form, and, when it does, it can be more readily detected and removed.

The Distribution of Liquor over a Baudelot Cooler. In cooling liquor or wort in a cooler of the Baudelot type, the even distribution of the liquor over the cooler becomes a matter of supreme importance, as it affects directly both the efficiency of the machine and that of the cooling. Generally speaking, the same principles apply as those which have to be observed with open air condensers. The wort or liquor must flow down the coils in a thin even film, and there must be no splashing or spattering. There is obviously a limit to the amount of liquor that will flow over the coolers without this happening, and the limit may be taken at about 100 gallons per lineal foot of distributing pipe per hour. In practice half this quantity, or 50 gallons per foot per hour, is all that is usually allowed for efficient work. The actual pipe surface employed for cooling depends, however, very much on the temperature to which the liquor has to be reduced. Much more surface has, for instance, to be employed if the liquor is being reduced 16° from, say, 50 to 34, than if it is being reduced the same number of degrees from 70 to 54.

In order to distribute the liquor over the coils, the practice, until recently, was to have a slotted pipe running the length of the cooler, and to introduce the liquor at one end of this, letting it run along and overflow through the slot over each side of the coils. This method, however, led to a very uneven distribution, that part of the cooler nearest the supply getting too much liquor, and that near the far end too little. Further, when the liquor was supplied to the cooler, as it often is, by a pump, the water would surge along at each stroke of the pump and would flow down the coils in waves. To overcome these defects, the liquor, in more recent practice, is introduced

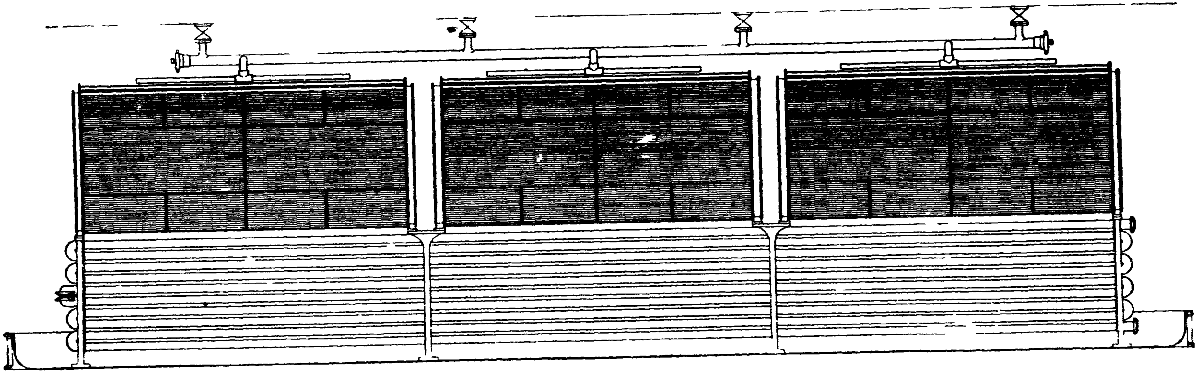

FIG 145

into a small tank placed in the centre of the length of the cooler, and is allowed to flow by gravity into the slotted pipe, and so over the coils. This method has got rid of the pulsation trouble, and has secured a much more regular distribution; but, even with it, if the cooler is at all long, the centre gets too much and the ends too little. The difficulty may be best met by having two or more tanks placed at even distances along the length of the cooler, the supply being regulated so that each part of the cooler gets its proper amount of liquor.

Iced Liquor and Direct Expansion, Baudelot Cooler for Wort and Liquor. A Baudelot cooler for cooling wort is illustrated in Figs. 144, 145, and 146.* The upper coils, which are of flattened copper pipe, are cooled by well or iced liquor, and the lower coils, which are of 2 in. bright steel pipe, by the direct expansion of ammonia. In accordance with the law that at a given temperature, range, and velocity, more heat is transmitted at the higher temperature, and in order that the wort, as it is cooled, may come in contact with still colder liquor and so maintain the temperature range, the cold liquor enters these coolers at the bottom and leaves them at the top. The liquid ammonia is fed in at the top of the expansion pipes, and, evaporating as it runs through the coils, leaves them at the bottom. This latter is known as top feed, and, though in careless hands there is some chance of the ammonia reaching the compressor in an oversaturated state, causing it to act in exactly the same way as a steam cylinder does when the steam supplied to it contains water, the advantages of top feed are so obvious, and the risk is, comparatively speaking, so small, that it is nearly always adopted for this work. The same remarks apply to Fig. 147,* which is a Baudelot cooler for cooling liquor, for wort cooling, and attemperating.

The capacity of the two coolers illustrated is as follows: That shown in Fig. 145 is designed to cool 200 barrels of wort from 180 to 40° F. The well or iced liquor passing through the upper part of the cooler is at a temperature of 45° F., and reduces the wort to 60° F. The lower portion, with ammonia expansion, reduces it from 60 to 40° F. That shown in Fig. 147 is for cooling liquor, for wort cooling, and attemperating. The combined capacity of three coolers similar to that illustrated, is 100 barrels of liquor per hour cooled from 54 to 34° F. When erected, they are surrounded by an insulated casing in order to keep the warm air of the brewery from playing on the coils and giving up its heat to them.

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* Messrs. L. Sterne & Co., Ltd., Glasgow.

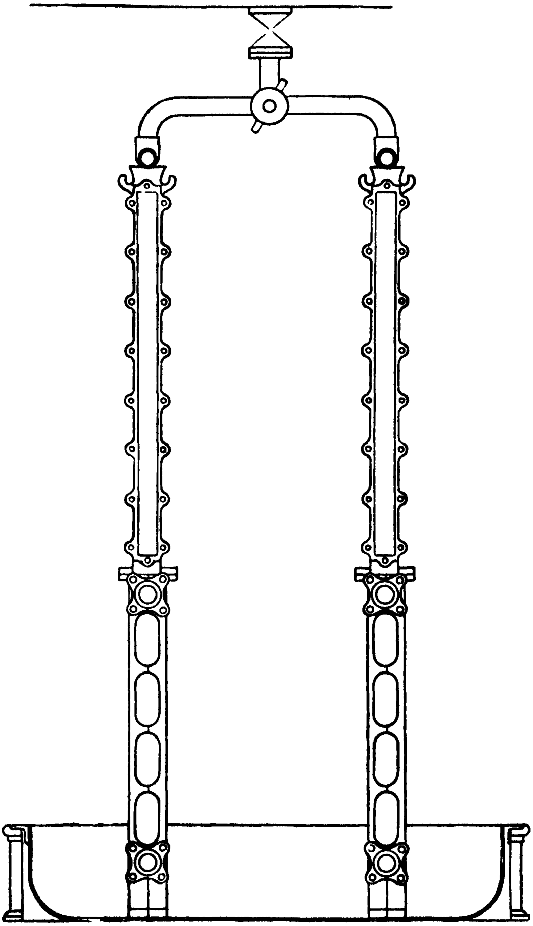

FIG. 146

If, instead of expanding ammonia directly into the lower

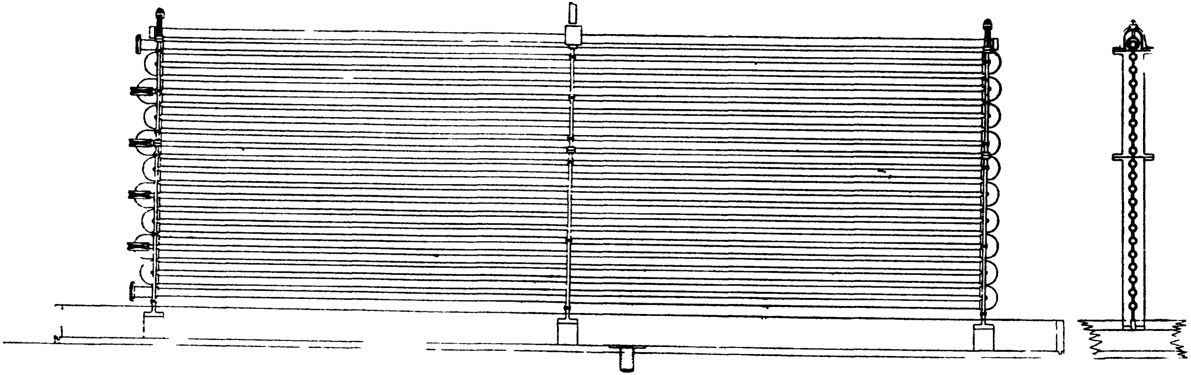

Fig 147

coils, it is preferred to circulate refrigerated brine, the same construction as shown in the figures is adhered to, the cold brine being fed in at the bottom and leaving at the top of the liquor cooler, and at the top of the ammonia cooled section of the wort cooler. Large numbers of this type of cooler using the latter medium have been installed in various breweries and have given good results.

Beer Chilling. When the beer leaves the fermenting tuns it is run into a skimming or underback from which it is racked into casks.

Most well brewed beers will become bright if kept for a sufficient time under proper conditions. The staple English beer is, however, the mild ale which is intended for consumption within about a week of brewing. This must be brilliant within a few days of racking and that result is obtained by adding finings, consisting of a solution of isinglass which coagulates in the beer, entraps the suspended particles, and carries them as a deposit either to the top or to the bottom.

There has during the last few years been a very great development in the bottled beer trade, and the brewer's aim is to produce a bright and sparkling bottled beer with which there is no sediment.

At one time all bottled beer was allowed to mature for some time in cask and then conditioned by a secondary fermentation in bottle, and this process is still followed with high-class pale ales and export beers, though as there is fermentation there must be some sediment in the bottle.

The process of carbonating was introduced to avoid this and to enable a quicker trade to be carried out, the beer being bottled in bright condition and then charged with CO_2. It is, however, impossible to prevent the development of fermentations and, consequently, of deposit unless the beer is consumed rapidly. There are, in the beer, a number of proteins more or less on the borderland of solution which may with changing conditions be thrown out of solution and cause the beer to become cloudy. The difficulty cannot be entirely met by filtration as the conditions that cause cloudiness may arise after bottling, but it has been overcome by chilling the beer to a temperature of about 32 or 33° F. when the solubility of these matters decreases so that they come out of solution, and by filtration at the low temperature they are entirely removed.

The chilling of the beer may be either effected in casks in a cold room when a period of about a week is required for the necessary reduction in temperature, or in special quick chilling cylinders. It appears to be generally agreed that the former method is the better, but the latter has the advantage of giving a quicker turnover, a smaller first cost and a reduced cost of working. The process of carbonating or charging with CO_2 is often combined with it, and owing to the low temperature of the beer it can be very readily and effectively carried out.

The process of chilling -whether slow or quick—then consists in cooling the beer from its normal temperature of about 60 or 65° F. to 32 or 33° F., the period of time and methods used being determined by the requirements of the individual brewer.

Lager Beer. In lager beer breweries much lower temperatures are carried all round ; the wort is in the first place cooled to from 45 to 40° F., the beer during fermentation is maintained at a temperature of from 45 to 50° F., and the room containing the fermenting tuns is insulated and provided with piping to cool it to the temperature of the beer.

The process of fermentation is generally similar to that described, but while in an ale brewery the yeast head rises to the top and the process lasts on the average for about forty-eight hours, the yeast used for lager beer produces a bottom fermentation and this extends for from six to twelve days.

After racking into casks these are placed in an insulated cellar cooled to a temperature of 35 to 40° F., where they are left for a period of some two to five months, during which the secondary fermentation and conditioning of the beer takes place.

With the low temperature the relatively low pressure of the CO_2 generated in the secondary fermentation causes the beer to become highly charged with gas.

When the casks are removed to the rather warmer cellars of the consumer, the gas pressure in the casks rises, with the result that when drawn off the beer foams in the glass. After a minute or so, when the foam subsides, it is remarkably clear, bright, and sparkling.

The figures given represent the average limits of the temperatures and lengths of time for fermentation and storage, but both of these may vary to a considerable extent with the different varieties of lager beer.

§3. Chocolate Cooling

The cooling of chocolate after manufacture is a very delicate problem if a good texture, finish, and absence of bloom is to be secured.

Before the days of mechanical refrigeration, chocolate was best made in the cooler months of the year, when the naturally low temperature would allow it to set and harden. This applied both to the moulded forms of chocolate and to the fancy and coated goods.

Chocolate is moulded at a temperature of about 83 to 90° F., and an air temperature of 42 to 46° F. has been found to give very satisfactory results for cooling bars. For covered goods a higher temperature of from 52 to 56° F. is carried.

The primitive method of cooling consisted in carrying trays of chocolate as it was made, and placing it in an ordinary cold room. Since that time many arrangements of coolers and special devices have been employed, but only the cabinet and the conveyor systems are in vogue to-day. In both, the actual cooling of the chocolate is effected by forced air circulation by means of a fan. The coolers must be of the dry pipe type where the cooling medium is inside the pipes. There must be no brine circulation over the coils if the air velocities are high, as there would be a danger of particles of brine being carried forward and deposited on the chocolate.

There is no difficulty with the dry pipe cooler, as a temperature of 40° F. is too high to permit any great accumulation of snow, which would block the cooler and put it out of action.

The air coolers may be arranged either for direct expansion or for brine circulation. The former is the cheapest where only one cooler has to be served, but where there are a number of coolers and possibly other duties for the plant, brine circulation is preferable, and it has, of course, the additional advantage that the refrigerating machine may be shut down for a short time and still run on the storage of cold brine.

For small outputs the cabinet system is convenient, and it has the advantage of the lowest first cost.

The cabinets are virtually small insulated rooms arranged with an air cooler, and fitted with guides, either of wood or of angle irons, which carry the wire trays on which the chocolates are placed.

These cabinets are sometimes arranged with a number of sections, each covered by one door. In this case gear is provided to close the air slots and stop the circulation of air through the compartment when the door is opened.

In other cases there are a large number of very small doors or, rather, flaps on the front of the cabinet. Each door covers two or three trays, and the object is to minimize the loss of cold air when the doors are opened and shut for the purpose of inserting and removing the trays.

With the exception of quite small outputs, however, the conveyor system is undoubtedly the best. The conveyor belt is arranged with its top at a convenient working height, and is constructed of two roller chains, one at each side, with attached slats, which are sometimes of wood battens, but are generally made of light perforated galvanized steel laths coupled together by links, making up an endless moving belt. This belt passes through a long insulated casing or trunk, built of wood and heavily insulated, the air cooler piping being arranged in the space beneath it.

Considerable experience is necessary in the design and construction of these coolers. It is obvious that there must be openings at each end for the conveyor and its load of chocolate, and that, with these openings, there must be some leakage of air in at one end and out at the other. The air leakage should, of course, be reduced to a minimum, but any escape of air should be at the end at which the cooled chocolate is discharged. Air entering from the outside should pass over the cooler before coming in contact with the chocolate, the coldest air meeting the coldest chocolate, otherwise there is a danger of the warm air condensing its moisture on the cold chocolate and spoiling it

A conveyor cooler lends itself admirably to a convenient layout and a well regulated routine in a chocolate factory. At the delivery end of the cooler the moulds as they emerge are automatically transferred to a belt running at right angles, which in turn delivers them on to a travelling band running either parallel to the cooler, or in any other position that may be desired. The girls take the full moulds from this belt as required, knock out the chocolate, and return the empty moulds to another belt running immediately above the first one. After the chocolates have been knocked out they are packed. The empty moulds are carried back to the feeding end of the machine, being heated on their way by passing through the heating chambers which are placed parallel to and adjoining the tapping tables. They are again filled and the cycle is repeated. The heating of moulds prior to filling is necessary, for though chocolate must be cooled fairly rapidly, it must not be poured into a cold mould.

The speed of the belt and the length of time that the chocolates are subject to the cold air must be varied to suit the thickness and bulk of the particular chocolates which are being passed through. For this reason the drive should be through variable speed gear, or by a variable speed electric motor. The cooler and packing room should be separated by a partition from the rest of the factory.

Enrober machines are now fitted with coolers—cold brine being generally employed, so that the chocolate can be set rapidly after it has been dipped and decorated. An Enrober machine with coolers is illustrated in Fig. 148.* The centres are placed on the belt at the near end of the machine, are coated by the machine, decorated by hand after leaving it, and cooled in the cooler shown in the distance.

In many systems of chocolate cooling there are considerable

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* Messrs. Baker, Perkins, Ltd., Peterborough, England.

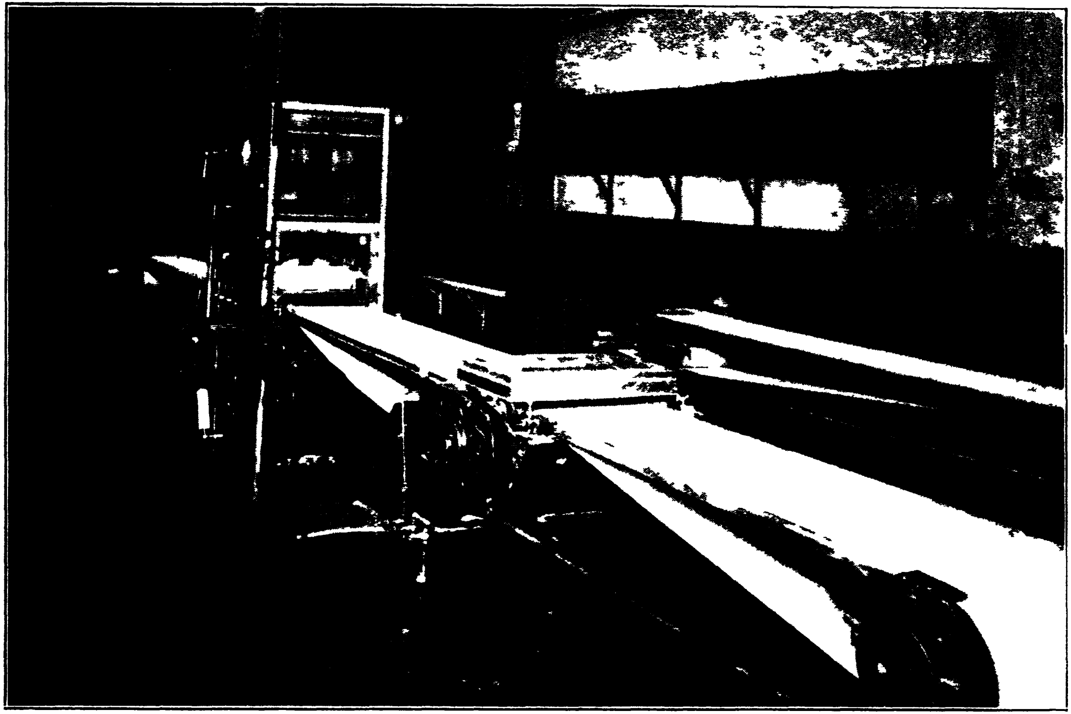

FIG 148

losses of cold air. In addition to the chocolates the moulds themselves have to be cooled, and a usual allowance in determining the refrigerating power required is to provide a capacity of 80 to 90 B.T.U. per lb. of chocolate.

A chocolate cooler* which is used in most modern chocolate factories consists of the filling machine, which automatically fills the moulds with a measured amount of semi-liquid or paste chocolate. Then come the tapping tables, where the chocolate is shaken down level in the moulds, then the cooler. The delivery end of a similar machine which was installed in a chocolate factory designed by the author is shown in Fig. 149. This illustration clearly shows the two air circulating fans, the delivery apron and the transfer belt, which is peculiar to this make. The knocking out belt is shown running parallel to the machine, with the belt for the empty moulds running at a higher level. The brine pipes supplying the refrigeration are shown overhead. The photograph was taken during erection before the pipes were covered with their insulation of sectional cork and white cement finish.

In the filling and packing rooms, and also in the hand-coating rooms, a difficulty is often encountered in hot weather from perspiration of the workers' hands. Some skins are more sensitive to this than others, and the workers are generally carefully selected from this point of view. In any case, an air cooling and conditioning plant is of great value, as by its use complete control of the atmospheric conditions can be maintained.

This is extensively used in the United States, where the great advantage of a constant and low relative humidity under automatic control is appreciated. The principles underlying the cooling of air are explained on pp. 406–9.

The usual method of de-humidifying is to draw pure air from the outside of a building by a fan, pass it through a chamber, where it comes in contact with sprays of very finely atomized water. This water cools and cleans the air, which then passes away through trunks into the building. Arrangements are made so that the air can be used over and over

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* Messrs. Baker, Perkins, Ltd., Peterborough, England.

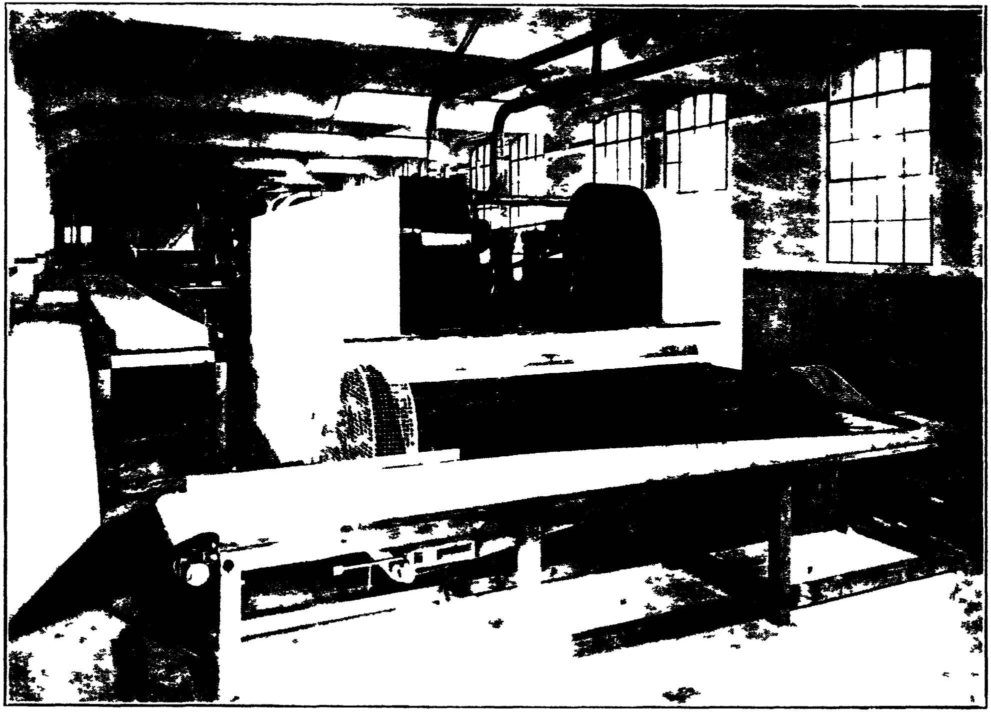

Fig 149

again, fresh air only being admitted as required. The temperatures required in the rooms are not low, but with the highest conditions of temperatures and relative humidity with which it is permissible to operate, it is necessary to have water at a temperature not exceeding 44° F. Mechanical refrigeration has consequently to be installed to cool the water. This is done in the ordinary way by letting it flow over a Baudelot cooler such as that illustrated in Fig. 147, p. 426.

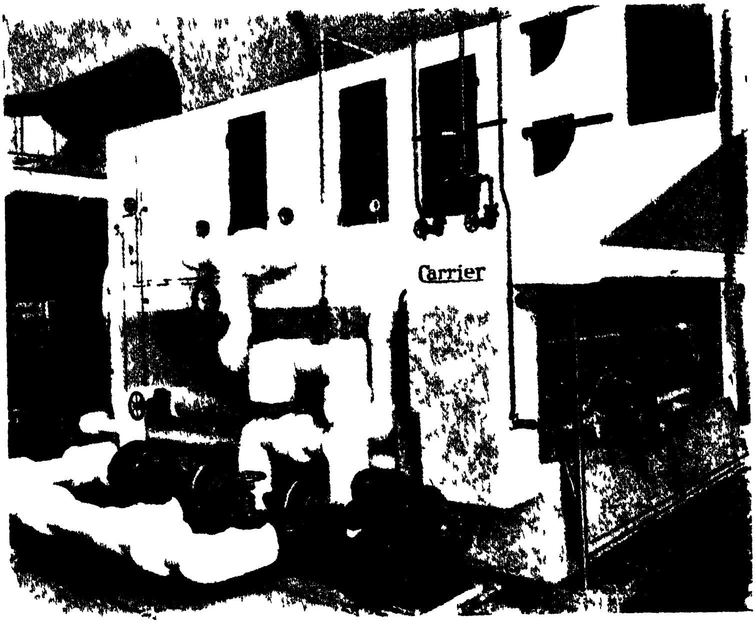

FIG. 150

Fig. 150* gives a general idea of a de-humidifier. The water spray for cooling and de-humidifying the air is in the upper chamber, while the refrigerating coils for cooling the water for the sprays is in the lower. Fig. 151† illustrates a room in a chocolate factory with conditioned air. The air ducts can be seen passing round the walls.

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* The Carrier Engineering Co., Ltd., London.

† *Ibid*

The great advantage of a mechanically controlled atmosphere is that it can automatically be kept constant at any temperature and humidity required.

§ 4. Explosive Manufacture

Refrigeration is largely employed in the manufacture of explosives. In nitration of glycerine a large amount of heat is generated which it is necessary to remove, in order to prevent combustion and explosion of the product during the process of manufacture

FIG. 151

The heat generated in the chemical reaction is removed by circulating brine, cooled by a refrigerating machine, through lead pipe coils placed in the nitrating pans. The refrigerating plant is often arranged with a large brine storage or accumulator tank, for unless the factory is dealing with a very large output so that a number of nitrations can be run in series, the load is very irregular. As a general rule also, the plant itself has to be placed at a considerable distance from the nitrating house, and allowance must be made for losses from the long pipe leads.

Refrigeration is also used in cordite factories both to cool water used in the washing process, and for the recovery, by condensation, of the volatile solvents.

§ 5. The Freezing of Food Products

If meat or fish, or within limits, eggs, are frozen hard, they can be kept almost indefinitely, so that freezing is used when storage may, or must, be extended over a longer period than the food in question can be kept in chilled condition.

There is also the advantage, from the point of view of shipment, that meat when frozen hard can be stacked close so that it occupies a minimum amount of space. While steady temperatures must of course be maintained, it is not necessary to keep within such very small temperature limits as chilled shipments demand. This greater latitude considerably simplifies the arrangement and working of the refrigerating plant, and the permissible close stacking means a more economical use of the refrigerated space in the cold store.

The frozen meat trade was of great importance, particularly to Australia and New Zealand, because until recently both the distance and conditions there practically ruled out the possibility of chilled shipments, so that their export business had to be in frozen meat.

There is also another and very important aspect of this question, and that is the fact that with frozen goods it is possible to build up suitable reserves of food for use in time of war or other emergency. From this point of view alone it is of urgent importance that some method of freezing beef without the present disadvantages should be found.

The technique of freezing and any possibility of improvement are of particular interest, because it has been found that the cause of the drip which occurs when beef is thawed out arises in the process of freezing.

When a simple solution is subjected to a low temperature pure water at first separates out as ice, leaving the more concentrated solution still fluid. On raising the temperature this separation is reversed, the solution and water mixing together and the whole returning to its original state.

Animal tissue, however, is not a simple solution, but a colloid structure and, while there is a similar separation of water and formation of ice, the behaviour of colloids on freezing and thawing may vary to an almost infinite degree with their nature and complexity, so that they either may or may not be partially or wholly reversible.

In the process of freezing, the most important factor is that of the time taken. When this is very rapid, the water separated out is frozen as minute particles of ice, all entirely within the tissue. As the time increases, these particles, following the ordinary rule of crystals, coalesce in freezing, so that they become of appreciable size. They may be partly within and partly outside the tissue, or with very slow freezing the ice forms entirely outside the tissues, making a sheath around them, and with the formation of these large crystals there may be rupture of the tissues.

There is a phenomenon familiar to engineers and, to some extent, parallel with this in the case of iron ; when cast in chills the larger portion of the carbon remains in combined form and the graphite flakes are very small. With ordinary slow cooling the graphite separates out, collects into fairly large flakes, and the iron is of an entirely different structure to that which is chill cast.

As the rate of freezing controls the formation of ice so does the rate of thawing control the re-absorption of the resulting free water, and for the best results, thawing should be slow.

With sufficiently rapid freezing there should be no appreciable difference after thawing ; with ordinary slow freezing much of the water, instead of being re-absorbed, runs away, carrying with it dissolved protiens, salts, and colouring matter, which constitute the well-known drip from frozen beef.

The best frozen mutton and lamb, on the other hand, thaws out in so nearly a perfect condition that little improvement can be obtained.

The time of freezing with meat or any other substance, as has been shown for ice, increases progressively with an increase in the thickness. Thus beef requires some four to five times as long as mutton, and this quicker freezing of mutton is partly why it thaws out so much better than frozen beef, though the main reason is in the difference in the structure, and possibly, in the composition of the meat.

With ordinary frozen meat, approximately 75 per cent of the water content is frozen, the balance remains as a more highly concentrated solution, and it would be necessary to reduce the temperature to about 70° F. to freeze the whole of the water.

So far as the time element is concerned, it would appear that there is a critical rate of freezing below which the condition of reversibility on thawing is obtained, but this for an object so large as a quarter of beef is such that it is impossible to attain with ordinary commercial methods of freezing in air or in salt brine solution. Further, while in experimental work, small pieces of meat have been frozen successfully by immersion in brine, there is always a penetration of salt into the surface which remains unfrozen, so that the appearance is bad. This is a fatal objection despite the fact that the meat, as a whole, thaws out better than that frozen in the ordinary way.

The time element is not, however, the only factor, as one of the remarkable features of living matter is the way in which substances that are ordinarily highly insoluble are held in solution, and freezing may throw these permanently out of solution.

In their investigations on the subject of freezing, the Food Investigation Board have found a notable exception of the time factor rule in the case of eggs, which are referred to in detail on page 366.

The average freezing point of egg yolk is 0·65° C. (30·83° F.), and of the white 0·45° C (31·19° F.). On freezing eggs at any temperature above 6° C. (21·2° F.), the eggs on thawing return to their original condition irrespective of the time of freezing. If, however, they are frozen at a lower temperature or, if after freezing at above 6° C., they are reduced to a lower temperature, say,–11° C.,(12·2° F.), the yolk is completely altered in character. Instead of returning to its original fluid state it remains in a soft and pasty condition and, when cooked, assumes the character of india-rubber.

This statement may be verified by anyone interested and sufficiently courageous, by merely asking for curried eggs at some of the cheaper restaurants !

Fish. It is perhaps not commonly realized that the fresh fish consumed at a London dinner table has probably been dead for several weeks before it is cooked.

All trawlers carry their supply of ice, and the provision of this ice in a crushed state is practically the sole reason for the existence of the large ice factories at the principal fishing ports. The consumption of ice on a trawler probably averages fifteen tons a week, so that when several hundred trawlers are using a port during the height of the season, the output of ice required is very large.

Experiments with germicidal ice have been made from time to time, but recently considerable success has been achieved at Seattle* with a process perfected by Lawrence Frandsen. It consists of impregnating the water before freezing with a chlorine compound. This kills the bacteria in the fish, and in recent tests it was found that the bacteria count was only about 1 per cent of the normal with untreated ice.

The fish when caught and cleaned is packed in the crushed ice, and becomes chilled, though the cooling, instead of being carried out by mechanical refrigeration, is effected by actual contact with the ice.

Trawlers have, in some cases, been fitted with their own refrigerating plant to avoid the use of ice. It appears probable, however, that the refrigerating power required demands a larger unit than can conveniently be installed on such a small vessel. On trawlers which proceed on extended voyages into warmer waters, a small refrigerating plant is very useful as a means of conserving the ice supply. The temperature of melting ice, i.e. 32° F., is favourable to the development of a number of bacteria, so that there is often a considerable odour in fish holds.

The preservation of fish in ice or in a cold storage room at about 30 to 35° F. is quite satisfactory during the normal interval required for distribution and retailing in this country.

In many countries fish has to be frozen, but the short distances and regular supplies in England make it unnecessary. It seems probable, therefore, that the possible returns would not justify the expensive and powerful installation which would be required to take care of occasional gluts.

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* National Antiseptic Inc., Seattle.

Salmon comes under rather a different heading, partly because of its greater value, partly because it stands ordinary freezing better than most fish. The season or period of run is of limited duration but it is well defined and of appreciable length. The localities where the greatest supplies are available are far removed from the main centres of consumption and without freezing, transportation would, in many cases, not be possible.

The dry freezing of fish in cold rooms has given rise to many disappointments. The product has been discredited on account of the loss of condition and flavour which results from the process of slow freezing, the peculiarities of which have been discussed.

By freezing sufficiently rapidly the texture can be kept virtually unaltered. There is probably no appreciable loss of flavour, though the determination of this point is not a simple matter, as it appears that flavour is determined by the presence of substances of which we have as yet no definite knowledge.

Immediately after death the muscle substance undergoes a change of state leading to the condition known as *rigor mortis*, when the whole body becomes rigid. Following this there is the slower chemical breakdown of autolysis when the muscles again become soft. After death the chemical composition of the tissues is subject to a continual change, and flavour, being presumably a function of the chemical composition, should follow similar changes. The condition of freshness and suitability for the palate becomes, therefore, one of degree.

With meat, after slaughter, a period of hanging is necessary. With fish, the sooner they are eaten after they are taken from the water, the better they are.

In practically all cases the state of *rigor mortis* is passed before fish can be brought to a freezing works.

The rate of freezing of fish or, in fact, of any other solid body, depends upon its bulk and thermal properties, also upon the thermal properties of the cooling medium, the rate of cooling increasing with the temperature difference and with the conductivity, specific heat, and the rate of circulation or agitation of the cooling medium. In practice it is found that, with equal temperature differences, the rate of freezing in brine is from fifteen to twenty times that at which the same fish can be frozen in air.

Air Freezing. There are a number of large fish freezing works on the North American and Canadian coasts. These are arranged at the water side so that the fishing vessels can come right alongside, and the fish, after washing, is elevated to freezing rooms on the first floor, and when frozen dropped to storage rooms below.

The freezing rooms are cooled to about minus 5° F. and even lower temperatures. There are a number of rooms which are filled and emptied in rotation. They are cooled by piping arranged in the form of shelves. The pipes are pitched some 9 to 10 in. apart, and the fish to be frozen is spread out on wooden trays which are placed directly on these shelves. After freezing the fish is glazed by dipping it into a tank of water maintained at a temperature of about 32° F. This covers the fish with a film or envelope of ice, which keeps it in good condition by preventing evaporation and drying up in the storage room. The water glaze slowly evaporates so that for very long storage it might be necessary to re-glaze at some period. In any case, re-glazing is generally effected before shipment.

There is never any artificial air circulation in the rooms, as this would cause too rapid an evaporation of the glaze, and would be fatal to success. A constant temperature is essential, and if the temperature of the fish is allowed to rise no attempt should be made to cool it down.

It is found that fish frozen hard and stored at 10° F. will keep good for very long periods, but that if it is stored at 20° F. it cannot be kept for more than a few weeks.

On account of the very low temperatures, large compressor capacity is required, and both the freezing and storage rooms must be heavily insulated. Both direct expansion and brine piping have been used, but the latter appears to be generally preferred on account of the simplicity and ease of regulation.

Brine Freezing. The freezing of fish by immersing it directly in a solution of cold sodium chloride brine has been carried out to a considerable extent under the Ottesen patents. Other patents have been taken out by Henderson and Dahl, while lengthy investigations into the freezing of fish by this method have been carried out with a small plant at Billingsgate Market by the Food Investigation Board.

In the Henderson process the cooling is carried out in two stages. In the Dahl process the fish is not immersed in brine but it is subject to a rain or sprinkling of brine which may be obtained at the required low temperature, either by the use of a refrigerating machine or by using ice or snow and salt.

The Ottesen process is the only one that has been adopted on any considerable commercial scale. The patent claims " a method of freezing or refrigerating comestibles characterized by the fact that the liquid at the beginning of the treatment contains easily accessible latent cold in the form of ice." It is stated that with this process the penetration of salt into the fish is prevented, but there seems to be some doubt on this point.

The fish, after washing, is spread out on wire trays which are assembled together in a frame, picked up by a crane, and immersed in a cold brine tank. There are several of these tanks which are used in rotation, the brine circulated through them is cooled in the external evaporator of a refrigerating machine.

At Billingsgate the fish was, in the first place, dealt with in a somewhat similar manner. As it naturally tended to float, it was found that there was a considerable difference in the rate of freezing, because some of the fish which was closely surrounded by others did not get in contact with the brine, and took a long time to freeze.

In a later arrangement the fish was placed in a perforated drum with a door constructed in a portion of its circumference like a washing machine. This was slowly rotated in the cold brine tank, the movement ensuring proper access of the brine to all of the fish and consequently an even rate of freezing. When the drum was elevated and the door opened, the frozen fish fell out on to a shoot, from whence it was taken and packed into boxes for storage or delivery.

At a fish freezing works constructed at Lorient the freezing tank was made of considerable length. The fish was passed into it at one end and taken through it, by means of a conveyor, which kept it immersed for the time necessary for freezing. When it left the conveyor at the other end it floated to the surface, and was easily collected and taken into the storage rooms.

Fish frozen by immersion in brine is best de-frosted by placing it in tepid water. It is claimed that fish frozen by this process cannot be distinguished from fresh fish, except by the appearance of the eye, which shrinks in the process of freezing. This should be no material objection, as it is not eaten.

The slight impregnation with salt is not of the same disadvantage with fish as it is with meat. It appears to make it impossible to glaze them successfully, and the prevention of evaporation can be effected either by wrapping the fish in paper or by placing it in airtight boxes or containers.

The Food Investigation Board, who are so often quoted, state that if herrings are thawed out at once after being properly brine frozen, they cannot be distinguished from fresh fish, but that after storage the eye changes as already noted. White fish is, generically, more difficult to freeze successfully than fish which contain more oil, but if care is taken it is equally successful.

Quick Freezing

The process of brine freezing developed by Mr. M. T. Zarotschenzeff, and known as the "Z" process, is now being successfully used in this country, and a small cabinet designed for the freezing and storage of fish is shown in Fig. 152.

The process consists essentially in spraying finely atomized sodium chloride brine at a temperature of about - 5° F. into the freezing chamber, so that the fish or other products in it are held in a dense wet fog of the cold brine that is in rapid circulation.

The fish fillets or other products to be frozen are wrapped in waxed paper so that they are not brought into direct contact with the brine The brine used does not adhere to these wrappings, and, consequently, the goods may be packed direct into cartons The wrapping ensures that the products are not touched by hand or exposed to the atmosphere until they are finally unwrapped by the purchaser for cooking

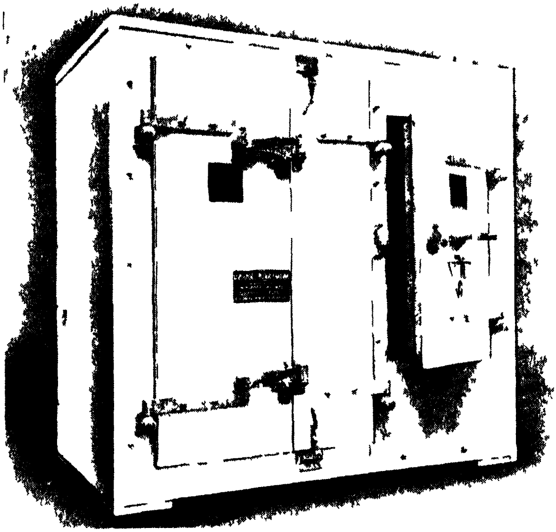

Fig 152

The "Z" process can also be applied to the chilling of fresh meat, using chilled water or a weak solution of sodium chloride It is claimed that the time required for this process is very greatly reduced, pig carcasses being chilled in 6 hours as against 24 hours in air, and also, that there is none of the shrinkage or loss of weight that occurs with the cooling by air in ordinary chill rooms

Other Methods of Quick Freezing. The process of quick freezing by immersion in brine is in use on some of the mother ships working with the fishing fleets off the North American Atlantic Coast, but it has not found general favour in the United States, and several installations erected on the Pacific Coast, both in the United States and in Canada, for freezing salmon have, after experience, given up brine freezing and reverted to the ordinary sharp freezer practice of freezing on pipe shelves in insulated rooms.

This reversion to the older practice has not been taken on account of any effect on the flesh of the fish caused by the freezing process itself, but on account of the penetration of salt that makes it impossible to glaze the fish, and what has been found more serious, that the brine frozen fish "rusts," or becomes a yellowish-brown colour, after three or four months' storage.

The advantages of quick freezing, due to the small size of the ice crystals that are formed, has been fully recognized. Attention has therefore been given to devising methods of quick freezing that do not involve direct contact between the brine and the product to be frozen, and with the aid of these an enormous development is taking place in the United States in the preparation, distribution, and sale of quick-frozen and packaged food.

This is not confined to fish, but includes meat, vegetables, and fruit. Fish is dressed and sent out as frozen fillets. Meat is prepared as chops and steaks, and vegetables are washed and sorted.

The rapidly increasing demand for these products is being fostered by the supply of carefully graded products of the highest class which require no preparation before cooking, and with which there is no waste.

To give such a service naturally requires the provision of plant which is expensive both to install and to operate. It is claimed, however, that the costs involved are offset by the saving which can be effected by dealing with the materials in bulk at the packing house, and by utilizing the by-products otherwise wasted in detail by the consumers. There is also a very great saving in the cost of transport.

The Peterson system of quick freezing was one of the first to avoid direct contact with brine, fish being frozen by packing them in moulds immersed in brine at – 20° to – 30° F., the fish being thawed out and emptied from these moulds in a similar manner to the ice in an ordinary ice-making plant. The fish are tipped from the moulds into a tank of water for glazing, after which they are passed to the storage room. The process of freezing is reported to have been satisfactory. but considerable difficulties arose from the block freezing of small fish.

In a system used by the Atlantic Coast Fisheries dressed fillets are frozen on metal trays that form part of a long conveyor, the trays having deep fins on the underside that drip into a brine tank under. In the Kolbe system, used at the Quincey Markets Cold Storage, Boston, and in other places, the dressed fillets are placed in circular pans that float on the cold brine, passing through a channel having a length of about 450 ft. arranged as a labyrinth to keep its dimensions within reasonable compass.

With both of these systems brine at a temperature of – 20° F. is used, and fish fillets are frozen in from 30 to 40 minutes. The freezing by contact with the cold surfaces proceeds only from one side, and the conditions are really somewhat similar to those obtaining in the ordinary sharp freezers, so that it might be assumed the ice crystals would be large on one side of the fillets. Both methods give satisfactory results in practice, however, probably owing to the fact that the prepared fillets dealt with are relatively thin.

The most highly developed process of quick freezing without contact with brine is the Birdseye system, invented by Mr. Clarence Birdseye and operated by the General Foods Co., Gloucester, Mass., U.S.A., in several plants which deal separately with fish, with meat products, and with fruit. Mr. Birdseye's attention was first drawn to the subject of fish freezing when he was engaged in the fur trade in Labrador. There he found himself surrounded with large quantities of splendid fish with no means of getting it, in a fresh condition, to the markets which were hungering for it. Experiment succeeded experiment, until, in a comparatively short time, he evolved the system which bears his name, and thus opened the way to a trade in frozen fresh products which, though of huge dimensions, is as yet only in its infancy.

The products to be frozen are prepared ready for cooking, are wrapped in Cellophane, and are placed between two travelling belts of Monel metal as illustrated in Fig. 153. The lower belts that extend outside the end of the casings are 36 in. wide, and are supported on ball-bearing rollers, so that their upper surfaces remain level. The products to be frozen are placed on them. The upper belts are shorter, and wider —42 in.—and are weighted so that they exert a pressure of some 55 lb. per square foot on the products. Being flexible, they adjust themselves to varying thicknesses.

As the belts travel, the products, which have been placed on the lower belt, are drawn in between the upper and the lower belt, and are subject to the pressure of the upper belt, thus coming into intimate contact with the metal on both sides. The freezing element is calcium chloride brine at the very low temperature of - 45° to - 50° F., this being directed on to the upper surface of the top belt through headers which traverse the machine. The upper belt, which, as stated, is wider than the lower one, is constructed with a bent edge to throw off the brine, so that it does not come into contact with the products. Brine is also directed on to the lower side of the bottom belt throughout its length, and in a machine 30 ft. long some 350 gallons of brine are circulated per minute. The belts are enclosed in an insulated casing, only the feeding and discharging ends being open, and the speed of travel is regulated so that the products are completely frozen when they leave. The general principle is similar to that of the chocolate cooler illustrated in Fig. 149, page 434, and, though with a different object, to that employed in the annealing lehrs used in the manufacture of glass bottles.

The time of freezing varies, of course, with the product, chops and steaks taking some twenty to twenty-five minutes to pass through the machine.

For small installations, and for portable plants, a self-contained

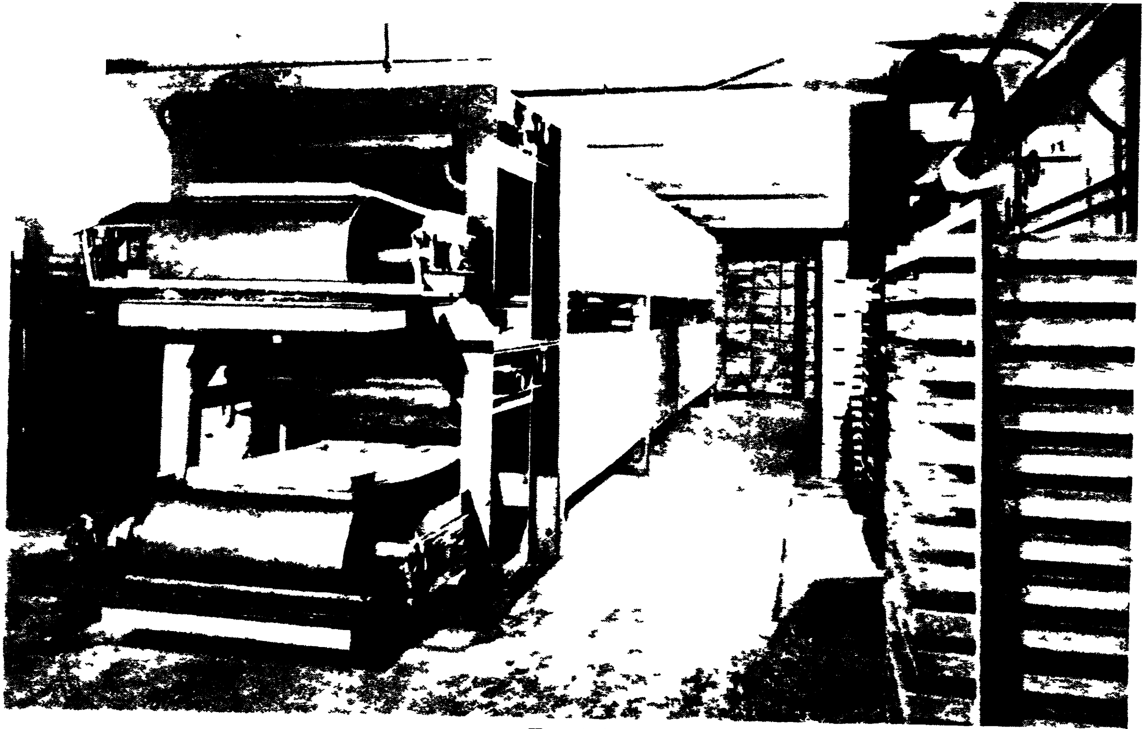

Fig 153

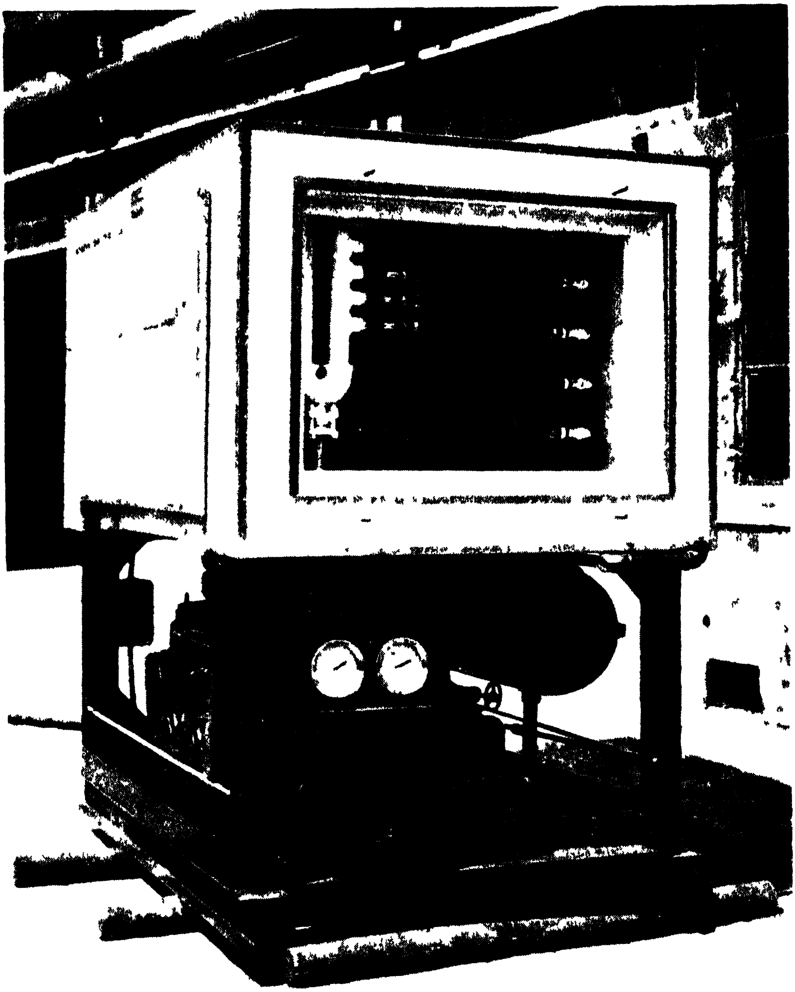

FIG. 154

multi-plate machine is used. This is shown in Fig. 154, and has a capacity of 7,500 lb. per 24 hours.

The cartons are packed in non-returnable corrugated fibre board cases, which have approximately the same insulating value as cork. These will keep the contents frozen for from three to five days, and it is therefore not necessary to use special refrigerated vehicles for transport for ordinary deliveries.

It is essential, of course, that the distributors should be provided with refrigerated display cases and storage spaces, and that the production ènd should be organized in the most thorough and scientific manner.

§ 6. Ice Cream

The extraordinarily rapid increase in the consumption of ice cream, which has gone hand in hand with the development of the trade in improved methods of manufacture and a superior product, is placing it amongst the more important of the industries that are entirely dependent on refrigeration.

The increased production and consumption in England has followed very much the same course as that in the United States, and in its manufacture the technique developed there has been very largely used.

A few years ago the making of ice cream was largely confined to the itinerant vendor and to small scale manufacture by confectioners, hotels, etc., all of which worked on more or less the same lines, using the small freezing tubs with ice and salt. It is now produced under highly scientific methods in factories that are models of cleanliness and order, equipped with expensive plant, and capable at the rate in some cases of an output of many thousands of gallons a day.

The materials employed are largely milk, cream, butter, milk powder, condensed milk, sugar, and gelatine. The materials to be used for any particular batch are mixed together for preparation prior to freezing, and are then referred to as the " mix."

It should be the aim in any factory to obtain a mix that will give a practically standard analysis and ice cream of a consistent type. While it is seldom that more than two or three milk products are used in any one batch, this result can be obtained by proper proportions of the various possible ingredients, and enables the manufacturer to utilize those of which there is the best supply at the moment. To do this, of course, involves a knowledge of the analysis of available materials in order that the correct proportions of each are employed.

A typical ice cream mix as developed in present practice will show on analysis some 32 to 35 per cent of total solids, made up as follows--

Butter fat	8 to 10 per cent
Milk solids, not fat	11 to 12 ,,
Sugar	13 ,,
Gelatine	0·5 ,,

The remainder is water, and while a considerable amount of water is supplied in the milk used, it is nearly always added to obtain the desired proportions. The gelatine is used to increase the viscosity of the mix and, while the proportion is small, its effect is most important.

It will be seen that the food value of ice cream is high, and this fact, coupled with the high quality of the product and skilful advertising, has greatly assisted the development of the trade.

In an ice cream factory refrigeration is in the first place required to chill storage rooms for the fresh milk, cream, and butter used in the process. These rooms are generally arranged at the top of the building so that the materials can travel down by gravity in the process of manufacture. The mix, when prepared, should first be pasteurized to eliminate any objectionable bacteria. The process is similar to that employed for milk, and consists of heating it by steam or by hot water to about 145° F., and holding it at that temperature for thirty minutes.

After pasteurization the mixture is passed through a homogenizer, Fig. 155. It will be seen that it is virtually an hydraulic pump which forces the mixture through a spring loaded valve, at a pressure of 2,000 to 4,000 lb. per sq. in. The process breaks up the globules of fat into very fine particles, thoroughly incorporates them in the mix, and goes a long way towards producing the smooth and velvety cream that is aimed at.

On leaving the homogenizer the mix should be cooled down rapidly to 45 or 40° F and passed into the ageing vats, where it is maintained at that temperature for from sixteen to twenty-four hours

The process of ageing is important in improving the flavour and increasing the viscosity of the mix, the change in composition being somewhat similar to that which occurs in the manufacture of butter and cheese Both in the mixing, pasteurizing, and ageing vessels the mix should be thoroughly but not too rapidly stirred

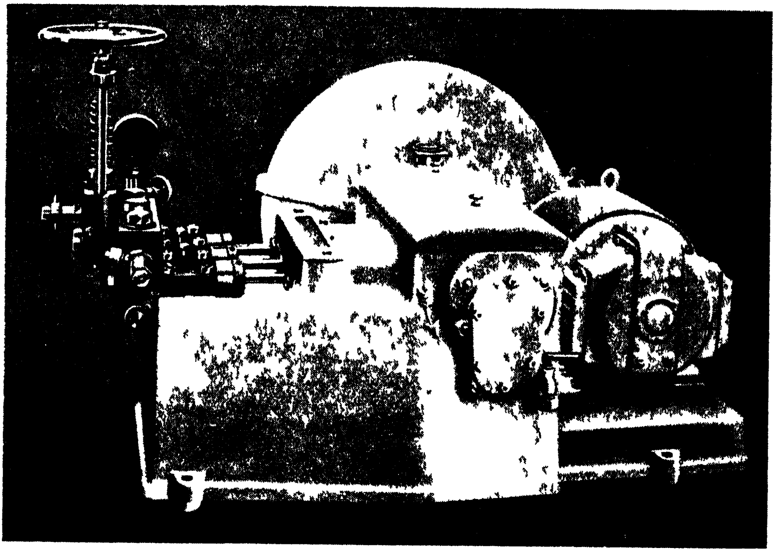

Fig 155

Various forms and types of vessels have been used for the processes of mixing, pasteurizing, and ageing Glass-lined steel tanks, as illustrated in Fig 156,* jacketed for the steam, cooling, water or brine that is used, are considered to be the best These tanks are fitted with a circulating propeller, for it is important that the mix should be thoroughly, though not too rapidly, stirred

The mixing and pasteurizing are generally effected in the same vessel, which can also be used for cooling and ageing when a homogenizer is not used.

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* Enamelled Metal Products Corporation, Ltd, 56 Kingsway, London, W C 2

Separate vessels, however, are generally used for ageing, and the cooling is often carried out on a flat cooler similar to those used for milk. From the ageing vats the mix passes to the freezers, where the flavouring essences, colouring matter, fruits, etc., are added.

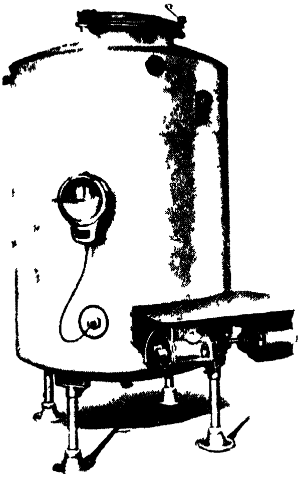
Fig 156

The freezer, Fig. 157, is generally a horizontal vessel jacketed for brine circulation and fitted with scrapers to remove the frozen mix from the surfaces. Beaters are also fitted which run in the opposite direction to the scrapers. In addition to thoroughly mixing up the charge that is being frozen, the action of the beaters causes a certain amount of air to be incorporated and retained as minute bubbles. This increases the volume of the mix while it is being frozen and is generally referred to as the overrun or swell.

The amount of overrun that is desirable varies to some extent with the composition, but averages about 80 per cent; that is to say, 1 gallon of mix will make rather over $1\frac{3}{4}$ gallons of ice cream.

The brine circulated through the jacket of the freezer should be at a temperature of about 5° F. The mix is quickly reduced to about 27° F. and is then in a semi-solid state. The freezing of the mix is what might be called the critical operation. A really good velvety ice cream of good flavour is only obtained if the particles are very minute indeed. To get these minute particles the freezing time must be very short—a small fraction of a second. If the temperature is higher and the time required for freezing greater, it is not possible to get the same percentage of overrun, and the quality of the cream falls off. From the freezers the frozen cream is run into containers which are placed in the hardening rooms, where they should be left for two or three days, depending upon the bulk of the vessels. The hardening room should be cooled to 5 or 0° F., and is usually arranged with shelves of brine or direct expansion piping on which the containers or pots are placed. The containers are sometimes immersed in a cold brine tank in place of the hardening room, but this does not appear to be good practice.

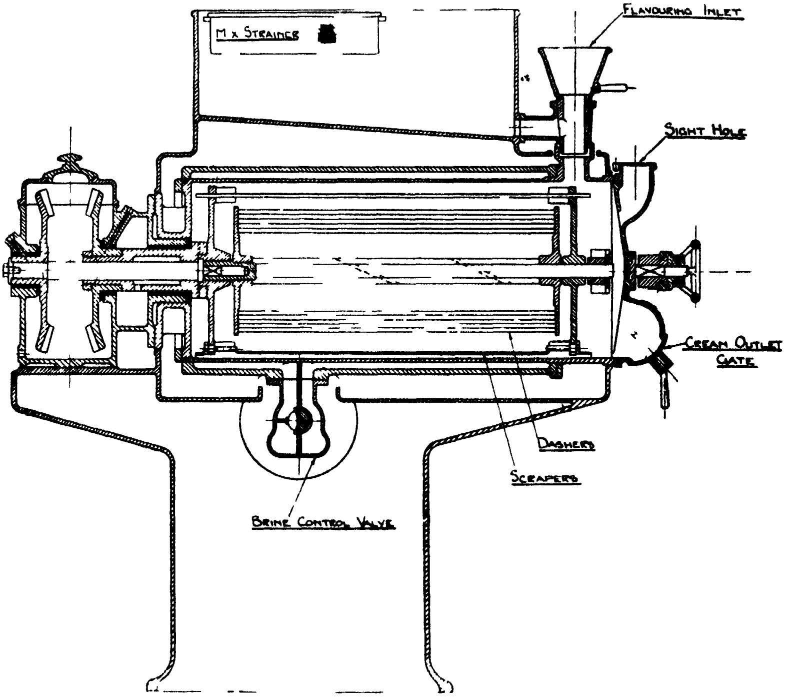

FIG. 157

The first method employed in making the ice cream bricks which are now so popular, was to run the cream into trays which were taken to the hardening rooms. When frozen hard they were cut up into sections of the required size and filled into cartons. The later practice is to take the cream from the freezers direct to filling machines, and run it into the cartons, which are then taken to the hardening rooms. This method probably reduces the labour and handling involved, but the former method is said to give the best results.

Many ice cream factories also produce a considerable amount of ice, which is crushed and used with salt for the storage of the cream while being transported to, and stored at, the retail distributing depots which the factory serves As pointed out elsewhere, this practice is rapidly being superseded by the use of solid CO_2 for storage, by mechanically refrigerated vehicles for distribution, and by the installation of small automatic refrigerators in retail depots.

FIG. 158

In any case, there is no difficulty in transporting ice cream It is regularly sent over long distances in America and in

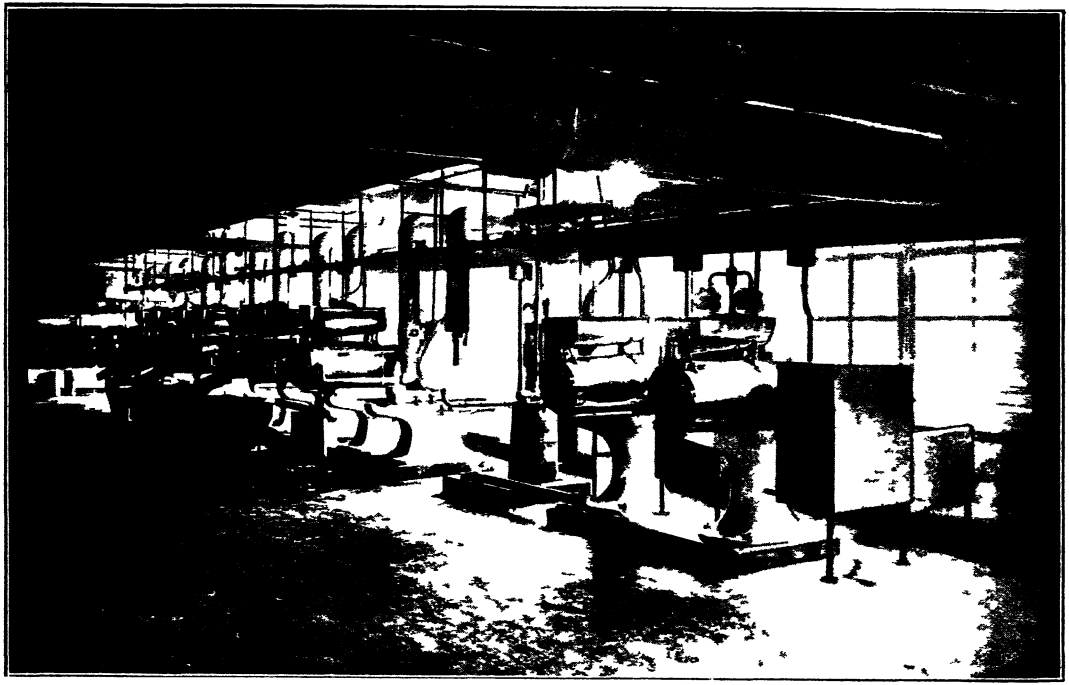

FIG 159

England; from London to Liverpool, a distance of over two hundred miles.

Figs. 158 to 160 are photographs taken in Messrs. Lyons' ice cream factory in London. Fig. 158 shows a group of ageing vats. Fig. 159 a group of ice cream freezers, and Fig. 160 girls packing the popular ice cream bricks.*

§ 7. Margarine

The basis of margarine was originally the oleo oil obtained in the meat works, mixed with milk, neutral lard, and often some quantities of butter and cream.

In present practice palm oil and other vegetable oils are largely used in place of the oleo. The milk as received is first pasteurized and cooled as in ordinary dairy practice. It is then passed into vats for the ripening process, which is usually effected by a starter or culture, in the development of which great care is taken. While the ripening process consists in the souring of the milk, it is most important that milk in the first place should be perfectly sweet.

At the correct stage of the development of the lactic acid the milk is churned up with the oil used, forming an emulsion. On issuing from the churns this emulsion is rapidly cooled down or, as it is termed, crystallized. It then assumes a granular form which, when tempered, is passed on to the kneading machines or butter workers, where it is worked up and becomes the margarine of commerce. It is packed into boxes or containers which are taken into a cold storage room, and should be held at a temperature of 32 to 35° F. for a day or two, so that it may have time to get thoroughly set before dispatch.

The usual process of chilling the emulsion is by means of water at a temperature of about 36° F., which is sprayed into the stream of emulsion issuing from the churn. Both water and emulsion pass down a shoot into a tank, from which the now crystallized globules are strained and lifted out by muslin cloths.

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* Figs. 155, 157, 158, 159, and 160 illustrate machinery manufactured by Messrs. Peter Brotherhood & Co., Ltd., Peterborough, England.

FIG 160

In another method which is used and patented by the Maypole Co., and commonly used in large plants, the emulsion is chilled by being run over large rotating drums through which brine at a low temperature is circulated. This crystallizes the margarine, which is continuously removed by means of a scraper knife.

Margarine is only profitable when manufactured on a large scale, and calls for very powerful refrigerating equipment. The bulk of the refrigerating power is required for cooling down the emulsion, and an average rule is to allow about 8 lb. of chilled water or, say, 90 B.T.U. per lb. of margarine. In addition, refrigerating power must be allowed for cooling the insulated storage room, and for cooling the milk when it is first brought in.

In the system of cooling on rotary drums rather greater thermal abstraction is required, and as this has to be effected at a very much lower temperature (the brine usually being at about 5° F.) it calls for a considerably larger compressor capacity.

§ 8. Milk Cooling and Preserving

Milk is an exceptionally favourable medium for the development and growth of bacteria. The rapidity with which this proceeds is largely dependent on the temperature.

To keep milk in good condition it is essential to maintain it at a relatively low temperature. A temperature of from 40 to 45° F. has been found to meet general and commercial requirements. The milk should, in the first place, be cooled at the farm. A refrigerating plant on the ordinary farm is out of the question on account of its cost, and the usual process is to pass the milk over a capillary or corrugated surface cooler through which the coldest water supply available flows.

On this type of cooler the milk passing over in a thin film is cooled rapidly. With the large volume (17 gallons) contained in the ordinary churn the rise in temperature, even in very hot weather, is slow, so that well cooled milk can be relied upon to arrive at the dairy or receiving depot in good condition.

Although there is still some controversy as to the merits of pasteurization, and it is argued that it should be unnecessary with good milk, there appears to be no doubt that, properly carried out, and with subsequent cooling, it is the best method for the preservation of milk. Early practice was to heat the milk to about 175 or 180° F. for a very short period. The tendency of modern practice is to heat the milk to 145° only, and to retain it at this temperature for about half an hour in jacketed vessels of large capacity. Hot water is used for heating, in place of steam, to avoid any risk of "burning" the milk.

In a modern dairy the milk is emptied from the churns, in which it arrives, into a receiving tank. From this it passes through a centrifugal clarifier which extracts every particle of foreign matter. It is then pasteurized and passed over a capillary cooler made in two sections, the upper portion using the coldest water supply available and the lower portion cold brine from the refrigerating machine.

From the cooler the milk passes into the churns for distribution or to bottle filling machines when delivery is made in bottles. That which is not immediately taken away on the milk rounds is placed in the cold storage room. An interchanger or regenerative heater is sometimes employed. The cold milk passes through it and is warmed up on its way to the pasteurizer and at the same time partially cools down the hot milk passing to the cooler. This interchanger may be placed between the pasteurizer and cooler, or between the receiving tank and the clarifier, as the latter works more effectively if the milk is at a temperature of about 100° F.

The function of a refrigerating plant in a dairy, therefore, consists in cooling the milk passing over the cooler and maintaining the storage rooms at the required temperature of about 40° F. Of these two duties the former invariably calls for the greater refrigerating power. As the operation of milk cooling is not continuous, but as a general rule lasts only for a few hours during the day, the load on the machine is a varying one. It is therefore always an advantage to have a large volume of brine in the system to act as a "cold" accumulator and absorb the excess work of the machine when it is running on the cold rooms only. This cold brine is available to help the machine when the greater load occurs during the period of milk cooling.

The volume of the brine tank will depend upon the capacity of the plant and length of time that the milk cooling occupies. In large dairies, where milk cooling occupies some four to five hours per day, it may be taken as a general rule that the refrigerating plant should have sufficient capacity to cool the milk through the required range of temperature at the rate which it passes over the cooler, and that the brine storage tank should have a capacity in gallons of about twice the number of gallons of milk to be cooled per hour.

The brine tank is frequently placed in the insulated room and thus serves, according to its size, either to wholly or to partially cool it. The better practice is to have a separately insulated tank and independent cooling piping for the room, so that fluctuations of the temperature of the brine in the tank will not affect the temperature of the room.

The coolers over which the milk is passed are constructed to cool it to within a few degrees of the cooling water or brine, so that the average brine temperature for the refrigerating plant will be between 30 and 35° F. It will be seen from the curves on pp. 144 and 145 that the output of the refrigerating machine, in thermal units, will be approximately 50 per cent greater than its output under the standard conditions under which the ton refrigeration is taken.

A machine of one ton refrigerating capacity will, therefore, under dairy conditions, give about 18,000 B.T.U. per hour, or be capable of cooling 90 gallons of milk per hour through 20° F. in continuous working. With a brine storage tank, and by running the machine for a longer time than the milk cooling occupies, a greater quantity can be cooled per hour.

The Cooling of Cream. If cream is churned at a temperature of 42 to 45° F., not only can larger returns be obtained from a given quantity, but a much better class of butter can be produced than if the cream is churned at the higher temperatures that rule in summer. For many years a temperature of 48° F. was aimed at, but as in most other cases, where refrigeration has been employed, the tendency has been to reduce the temperature and it is now considered that 42° F. gives the best results.

That there is a proper temperature for churning is, of course, housewife's knowledge, and in the old days churns used to be sold fitted with a thermometer and with jackets which could be filled with cold water in summer and warm water in winter. These were quite unsatisfactory, though perhaps better than nothing. In the modern creamery the milk is delivered by the farmers at a temperature of from about 65 to 70° F. in summer and 40 to 50° F. in winter. As in a dairy for the distribution of fresh milk, pasteurization of the milk, when received, should be the first step, and the present practice is to heat it to a temperature of about 145° F., and hold it at that temperature for about thirty minutes.

With an Alpha Laval separator separation will be complete at any temperature from 100° upwards, but generally it has been found that the cream will more readily separate from the milk at a temperature of 160° than at any other. Though they have nothing to do with each other, the high temperature which is necessary for pasteurization is desirable for separating, and two objects are thus attained by the one heating. After pastuerization and separation the milk is cooled down by being passed over a cooler of the Baudelot type very similar to those used in breweries for cooling wort—through which well water is kept running, and is returned to the farmers for feeding pigs, calves, etc. The cream is cooled rapidly by being passed over a circular capillary cooler, through the corrugations of which well water is circulating. This reduces its temperature to about 70° F., which is about as low as it is possible to get it with ordinary well water, though in parts of Ireland, notably County Kerry, the temperature of the springs is much lower.

The more rapidly milk is cooled, the better for it and the longer it can be preserved. It is, therefore, desirable to still further reduce the temperature of the cream to about 50°. In view of the fact that the subsequent ripening again raises the temperature of the cream to 70°, this cooling might appear to be unnecessary, but it is not so, as any tendency to bacterial activity and the absorption of aerial ferments is counteracted by it. At this temperature, then, the cream is placed in vats, where it ripens. Practically it ferments, and, due to this lactic fermentation, the temperature, as stated above, rises. In from fifteen to twenty hours the cream is ready to be churned, but, in order that the fat globules may not be broken and the butter become oily, and in order also that the yield may be as large as possible, the cream is again cooled either by being run over a capillary cooler on its way from the ripening vat to the churn or, more often in present practice, it is cooled in the ripening vat itself, which is constructed with a jacket for hot water for heating and with a revolving or swinging coil through which cold brine or iced water can be circulated. In some forty-five minutes churning is complete and the butter floats on the top of the whey in a fine firm condition.

This, then, is the process. The necessity for refrigeration will be seen in the low temperature which it is absolutely necessary to keep if it is wished to obtain the best results. It is desirable also to chill the butter and the milk before it is sent to market.

Fig. 161* illustrates a small refrigerating machine and plant for cooling milk or cream by means of a flat type cooler. The cream is run on to the distributing saucer from the ripening vats, and flows gently and evenly down over the wide flutings of the cooler into the collecting saucer at the bottom and away to the churn. Brine chilled in the evaporator of the refrigerating machine is pumped round through the flutings of the cooler and absorbs heat from the cream. The distribution of the cream over the cooler must be regulated so as to ensure its all being of an even temperature.

In some dairies the ripening vats are placed so as to command the churns, the cream being run from them over the cooler and into the churns by gravity. Where this is done, the regulation of the flow over the coolers is not difficult;

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* Messrs. William Douglas & Sons, Ltd., Putney, London.

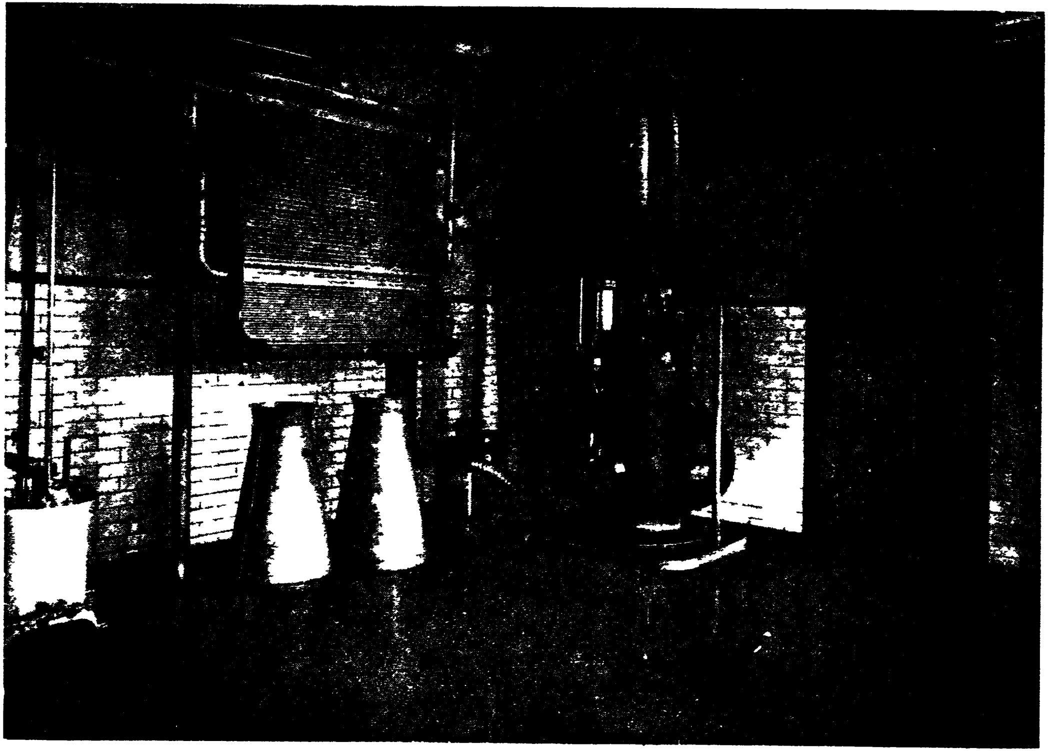

FIG 161

but where for some reason or other the cream has to be pumped, care should be taken to regulate the suction of the pump to give an even flow.

The essence of a successful dairy is cleanliness, and great care should be taken to arrange that every vessel in contact with the milk or cream can be thoroughly scalded down each time after it has been used.

§ 9. Mineral Waters

The quantity of CO_2 which water will absorb at a given pressure is greater at a low temperature than it is at higher ones. The higher the water temperature, the greater is the pressure of gas necessary for the process of carbonating and bottling. At the filling of each bottle a certain amount of gas is lost which, with a factory having a large output, may in a hot climate become a serious item in the working costs.

A refrigerating plant can, therefore, be applied with advantage to reduce the temperature of the water used for bottling when there are fluctuations in the general temperature. This has the advantage that aerated waters will always open up sparkling and in good condition, whereas waters bottled at a high temperature and opened at a low temperature will appear flat. There should only be a small reduction in temperature, or an excessive pressure will be generated in the bottles when they are warmed up to the normal outside temperature, and there may be considerable loss as well as danger through bursting bottles.

§ 10. Mortuaries

Refrigeration is applied in mortuaries to the preservation of human bodies that may be awaiting identification or an inquest, and most of the large hospitals are equipped in this way. The bodies are carried in trays which are usually supported three high on racks provided with rollers, so that the trays are easily handled in and out.

The best arrangement is to have a separate compartment with its own door for each group of three trays. The cost of plant and construction can be reduced by having two groups of six trays in each compartment, but in that case there must be two doors. If one door is used sufficiently wide to cover them both it becomes unduly heavy, and is liable to sag on its hinges.

The compartments or rooms in which the bodies are placed should be cooled to a temperature of about 30 or 32° F. The racks carrying the trays must be made removable. Any cooling pipes must be galvanized, and the construction and finish of the insulation must be such that the spaces can be thoroughly flushed out without any risk of damaging it.

§ 11. Paraffin Crystallization

During the process of distilling the natural oil shales, a number of spirits and oils of different specific gravities are obtained. With the more volatile kinds refrigeration is not concerned, but it is used extensively in assisting the crystallization of those which are solid at ordinary temperatures and which, when mixed with stearine, are extensively used for making candles. During the cold winter months no great difficulty is found in separating the heavy paraffin from the lighter oils as it will crystallize out, but in the summer months the temperature is too high, and crystallization will not take place to its full extent. One of the first applications of refrigeration was to cooling paraffin in the summer, and a large saving was made by Kirk's cold air machine, which was used for cooling oil in some works near Bathgate.

When the oil is cooled the paraffin wax crystallizes out, and it is then removed by forcing the oil through heavy filter presses. The temperature to which the oil is cooled depends upon the degree of extraction required, and varies from about 30° F. to as low as 10° F. Many forms of oil coolers have been used, and an essential factor in their design is that as the wax crystallizes on the cold surfaces it must be constantly removed to maintain the efficiency of the cooling surfaces.

One of the latest types is the Moore-Burmah oil cooler, patent No. 203160,* and illustrated in Fig. 162. This consists of a number of shallow circular cells erected in a vertical stand,

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* Messrs. A. F. Craig, Ltd., Paisley.

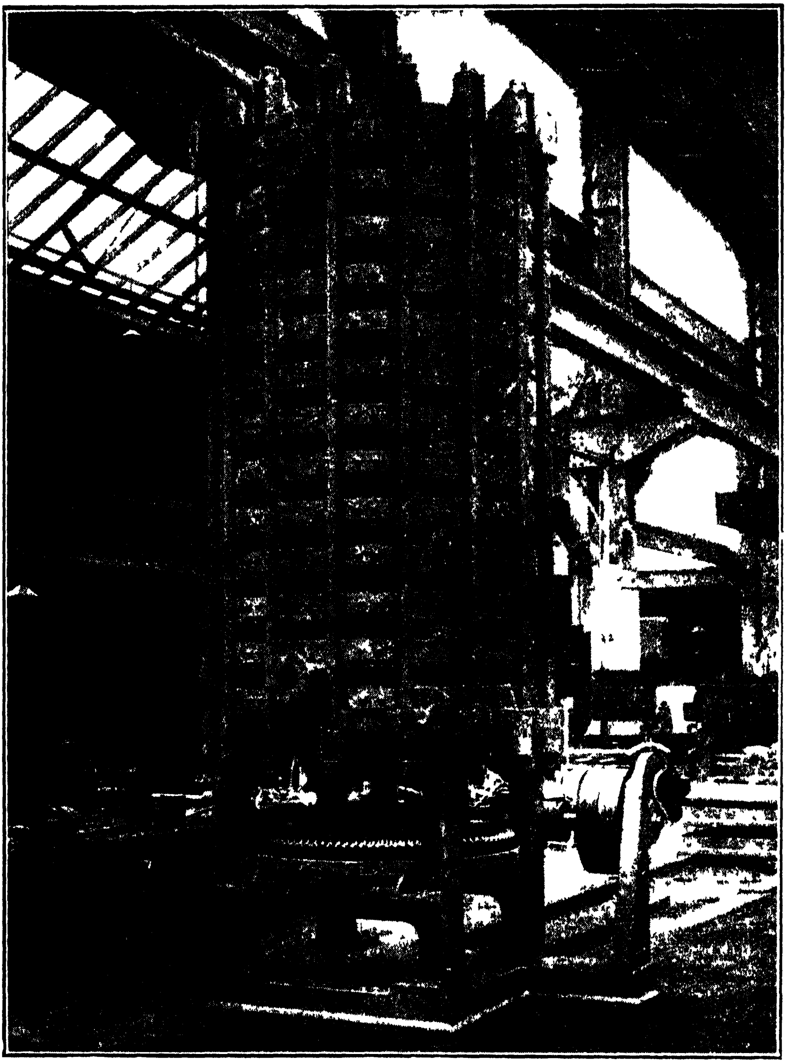

FIG. 162

each cell comprising two chambers. The oil flows through the upper and cold brine through the lower, while communicating passages connect the several oil and brine chambers which alternate throughout the stand.

The oil passes through its chambers in series from top to bottom, and the brine passes also in series through its chambers from the bottom to the top ; in this way the counter current principle is maintained, and the arrangement provides large cooling surfaces with a minimum exposed external surface.

The interior of the cells for the oil is machined, and the wax adhering to the surfaces is continuously removed by scrapers attached to a central shaft, which is actuated by worm gearing at the bottom. A twelve cell cooler, as illustrated, has a capacity of 1,500 gallons per hour, and requires about 5 b.h.p. to drive it.

The refrigerating machine is used to cool the brine for circulating through the machine, and consequently there is nothing special about it. Fig. 163* illustrates the refrigerating installation in the engine room of the Anglo-Persian Oil Co. at Skewen, South Wales.

In this case the heavy oil fractions from the distillation of crude oil are passed through interchangers, in which the incoming heavy oil is partly cooled by the outgoing oil from which the wax has been extracted. The heavy oil is then cooled, in two stages, in Thomson coolers. These coolers are vertical cast iron cylindrical vessels, fitted with an external jacket through which brine is circulated. The internal cylinder is provided with scrapers which remove the wax from the walls of the cylinder. The oil is pumped into the top of the cylinder, and the oil and wax pass out at the bottom into filter presses. There are two sets of coolers and presses to permit of cooling the oil in two stages. In the first stage the oil is cooled to about 25° F. and pressed at that temperature. In the second stage the oil drained from the presses is passed through the second set of coolers and presses where the operation is repeated at about 10° F. The wax is removed from the presses, treated in the sweating stoves to remove excess oil, and then filtered, decolorized, and cast in moulds.

The refrigerating plant consists of three horizontal double acting NH_3 compressors electrically driven through gearing, atmospheric condensers, and four tank type brine coolers .

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* Messrs J. & E. Hall, Ltd., Dartford, Kent

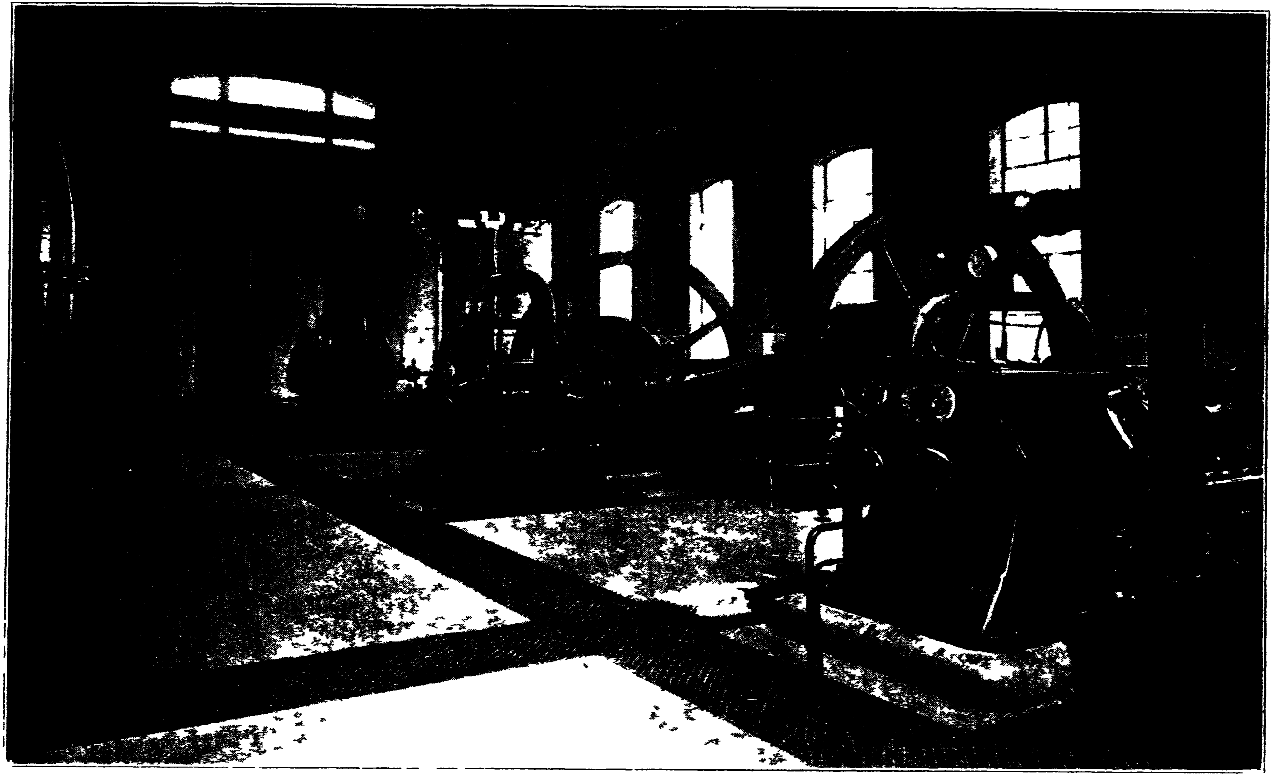

Fig 163

Two brine coolers and one compressor are used for each of the stages in cooling the oil, the third compressor being a standby. The Thomson coolers, which are insulated, are erected in an uninsulated building adjacent to the rooms, in which the filter presses are installed. These rooms are insulated and cooled by circulation of brine through grids on the walls and roof in the usual manner.

For producing the refrigerating effect in an oil refinery any type of refrigerating machine can be used, the type which is most suitable for a particular refinery will be determined by the general design of the refinery plant. In all refineries there is a large demand for steam at moderate pressures for distillation, and in some the main power plant consists of a steam turbine driving an electric generator. The whole of the subsidiary plant, such as pumps, refrigerating compressors etc., is driven by motors. With this arrangement the turbine is bled at a pressure suitable for the steam supply for distillation, and consequently the power required for driving auxiliaries is obtained at small cost.

In refineries distilling oil, containing a high percentage of wax, the refrigerating plant becomes one of the chief power absorbing elements and for economical reasons the compression type of refrigerating machine is driven by steam engines, exhausting at a back pressure suitable for supplying exhaust steam to the distillation plant. In the Unites States ammonia absorption machines are frequently used, the steam supply for which is obtained from the exhaust of the ammonia, water, brine, and other pumps.

§ 12. Pipe Line Refrigeration

Some of the cities in the United States have central station refrigeration, with pipe services either for brine circulation or for ammonia laid through the streets. This is connected up to the piping in insulated rooms of the various users throughout the area covered.

The ammonia absorption machine is stated to have some advantage for these installations, because of its capacity for dealing with considerable fluctuations in the load.

It has not been found practicable to devise any satisfactory system of metering to register the actual refrigerating power taken, and the charge has generally been based on the capacity of the room, the temperature required, and the general conditions of working.

§ 13. Rubber Manufacture

In a modern tyre factory, very large quantities of cold water are required for the rolls which break down the rubber. It has been found that if these rolls are too cold there is a power wastage. If they are too hot, the rubber cannot be worked.

The surface temperature of the roll that gives the best results is about 73° with most qualities of rubber, and this temperature can be obtained if such a quantity of water is circulated through the roll that its temperature on leaving is about 63°.

If there are wells giving a supply of water at not over 55° F. in the summer time, water cooling plant is not necessary, unless the supply is restricted. If, however, the supply is restricted, or the summer temperature is higher than the above figure, it pays to install refrigerating plant to cool the water down to, say, 45° F. If the water is cooled down to this temperature, less than half the quantity that would be required at 55° F. will suffice.

Where the water supply is very restricted, then the whole of the heat can be extracted by refrigerating plant and the water consumption reduced to a mere fraction of what it would otherwise be, the same water being used over and over again.

For certain purposes either ice cold water at about 38° F. or brine at about 25° F. is desirable. These temperatures are used by the manufacturers of rubber balls, moulded rubber toys, and similar goods.

Refrigeration is also used in connection with the air conditioning plant in a strand impregnating room, that is, where the cotton cords are impregnated with rubber solution.

When the cotton cords leave the cotton mill they contain a lot of moisture as the atmosphere within the cotton mill has to be kept relatively moist. Before impregnating with rubber solution, this moisture should be dried out, and hence the dry conditioned air and its necessary refrigeration.

The thin strips of rubber used for insulating electric cables and thin sheets used for other purposes, are cut from large solid blocks. In hot weather these become soft and tacky, making the operation of cutting impossible. They are, therefore, in the first place hardened by immersion in a tank of chilled water for sufficient time to cool them through, and a small stream of chilled water is also played on the cutting knives when these are in operation.

§ 14. Shaft Sinking

In sinking shafts through quicksands or water borne strata, where the inflow is so great that it cannot be met by pumping or excluded by compressed air, the freezing process has been successfully resorted to.

A number of shafts in Belgium and in Germany have been sunk in this way, and in England it has been used for sinking the shafts at the Washington and Dawdon collieries.

At Dawdon it was the water from the sea, passing through fissures in a strata of limestone through which the shaft had to pass, which caused the trouble.

Fig. 164* shows the heads of the freezing pipes for a shaft which was sunk to a very great depth in Belgium. As will be seen from the illustration, a ring of pipes is sunk into the ground from the surface through the water borne strata to the depth to which it is decided to carry the ice wall. Each pipe actually consists of two concentric pipes, the outer one being 4 or 5 in. diameter and closed at the bottom, the inner one being about 1¼ in. in diameter and open at the bottom. Both are connected at the top to ring main headers for the brine flow and delivery. The brine passes down through the inner pipe and upwards through the outer one, in course of time building up a solid wall of ice through the centre of which the shaft can be excavated and lined in the ordinary way with cast iron tubbing.

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* Reproduced from *Ice and Cold Storage*, London.

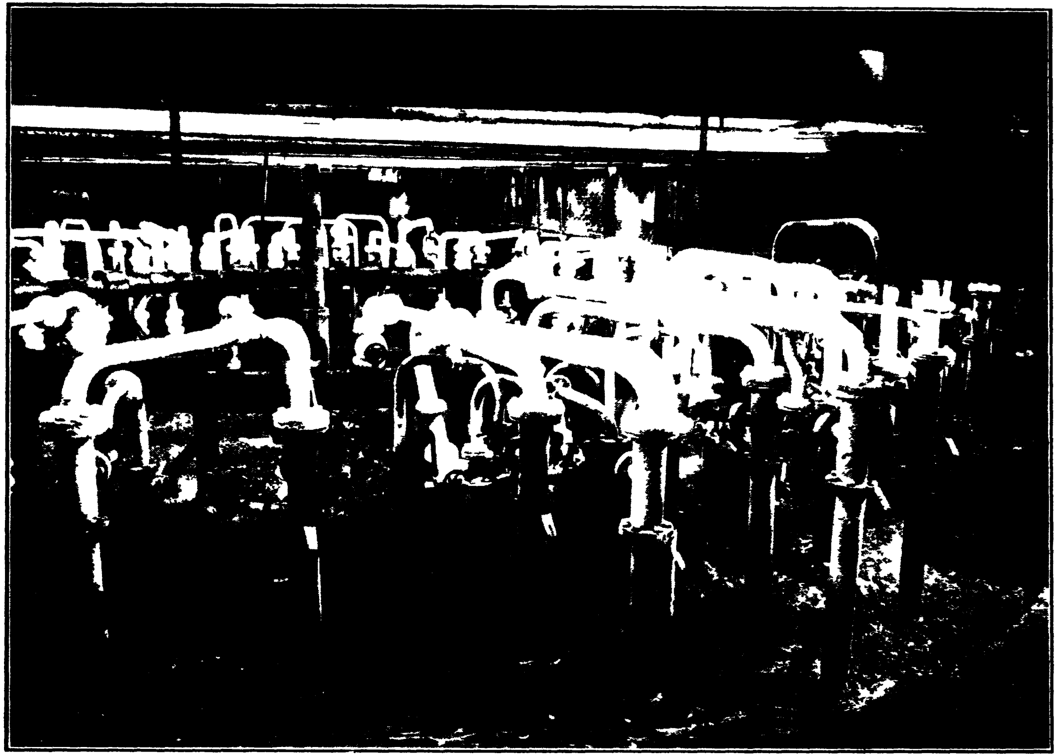

Fig 164

The pipes must naturally be driven as nearly as possible absolutely vertical. This calls for considerable skill. If it should be found that a pipe has deviated from the vertical to any considerable extent, it is advisable to sink another one near it, so that there may not be too great a gap between any two pipes at the point at which the freezing is actually required.

As a general rule the whole of the ground from the surface downwards is frozen solid. Where the water borne strata is at a very deep level, some refrigeration may be saved by, to some extent, insulating the upper section of the pipes. This also avoids the necessity of the work of sinking the shaft being carried out in an extremely low temperature, when from the nature of the ground it is not necessary.

The method of insulation adopted is usually that of driving a third pipe over the outer one to the depth required. The resulting air space serves as a partial insulation.

The wall or cylinder of ice must be of sufficient thickness to withstand the external pressure, which in the case of deep shafts may be considerable, as well as the stresses which may be involved through the process of sinking the shaft itself.

There is no serious difficulty in calculating the refrigerating power required when the depth to which the ice wall is to be sunk has been decided, and the composition of the strata is known. For though the water in it must be frozen and its latent heat extracted, the solid ground and sand or other matter, having no latent heat, has, of course, only to be cooled down from its normal temperature to the temperature of about 0 or 5° F., at which the ice is usually formed.

In the majority of cases it will be found that the water to be frozen is by no means pure, but has a certain amount of salts in solution, and is to some extent in the nature of a brine. Its actual freezing point will consequently be lower, depending on the strength of the solution.

In addition to the building up of the ice wall by the freezing process, the refrigerating plant has to maintain it until the construction of the shaft is complete, but it will naturally be found that the refrigerating power which is sufficient to build up the wall is more than ample to maintain it at its required thickness.

§ 15. Refrigerated Transport

Refrigerated wagons, insulated and cooled by ice, have been used for many years on railways, particularly those in the United States. In the great development of road transport during the last few years refrigerator lorries have come into their own, but like most of the refrigerator railway wagons in this country, they have consisted simply of an insulated body, or in some cases merely a ventilated one.

The aim and object of the vehicle has been to keep its contents cool during transport, and as the traffic in this country consisted mainly in distributing from dockside cold store to other depots or markets, this has been considered to have been successfully met if the internal temperature did not exceed about 45° F. for ordinary fresh produce, or about 30° F. for frozen meat, butter, etc.

The transport of ice cream and of hard, frozen fish or other products demands, however, very much lower temperatures, and the order prohibiting the use of preservatives has necessitated a degree of refrigeration for the transport of fresh cream when a journey or delivery round may last for several hours.

The use of ice and salt, originally employed for low temperatures, has many disadvantages. It is difficult to reach the temperature of about 5° F. required for ice cream, and the weight of the ice and salt is considerable. As the mixture is messy and highly corrosive, the upkeep charges are high, and any leakage may result in the ice cream being spoiled.

Low temperature may be obtained by the use of solid CO_2 or by mechanical refrigeration. The use of both methods are in the early stages of development, and as there is an almost infinite diversity in the conditions of transport, there is probably room for the use of both systems, and also for the continued use of ice for relatively high temperatures in railway wagons.

On road vehicles it is most important that the non-paying load should be as small as possible; hence, insulation should be as light as possible in order that the greatest proportion of the carrying capacity of the chassis is available for paying load, and the same consideration is true, though to a very much lesser extent, for railway wagons.

Alfol insulation* is therefore being used to a considerable extent for refrigerated lorries. This insulation consists of lightly crumpled sheets of very thin and highly polished aluminium foil built up in any suitable framework, using about three layers per inch of thickness. Applied in this way the weight of the insulation is only about 3 oz. per cubic foot, and by its use, a saving of approximately 15 cwt. can be made in the weight of the insulation for a lorry.

An Altek refrigerated railway wagon is shown in Fig. 165. This is an independent and self-contained unit which is not dependent on the movement of the train or on the provision of external supplies on long journeys that might, owing to interruption of time tables, occupy a period of from six to eight days.

The power plant consists of a Diesel engine, with thermo syphon cooling, driving a compound ammonia compressor, and a dynamo to generate current for the controls, etc.

The ammonia condenser and the radiator for the engine are air cooled and are constructed as a unit with a fan which circulates the outside air over them.

The car body is cooled by air circulation with a direct expansion air cooler and fan. Full automatic control is provided, and the thermostat not only controls the refrigeration, but is also arranged to bring electric heating elements into service if required. There are cases where this is absolutely necessary.

For instance, peaches loaded in Italy in September require refrigeration, but when crossing the Alps they require protection from frost. The specially designed automatic controls that are used in the Altek car are particularly effective, and thermograph records taken on long journeys, through wide

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* Alfol Insulation Co., Ltd., Windsor House, Victoria St., London, S.W.1.

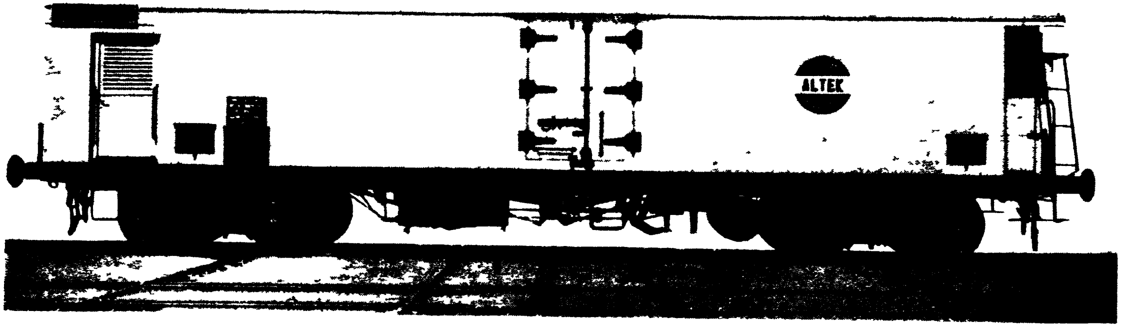

FIG 165

variations in the outside temperature, have shown that a remarkably steady temperature is maintained inside the car.

A mechanically refrigerated motor lorry is shown in Fig. 166, and the power unit, made by Messrs J and E Hall, Ltd., in Fig. 167

These wagons each form a mobile cold store which works entirely automatically whether the vehicle is moving on the road or at rest in any situation, and trials that have been carried out have established the ability of the refrigerating plant to maintain a temperature of from 0° F to 5° F. under service conditions and during the hottest summer weather.

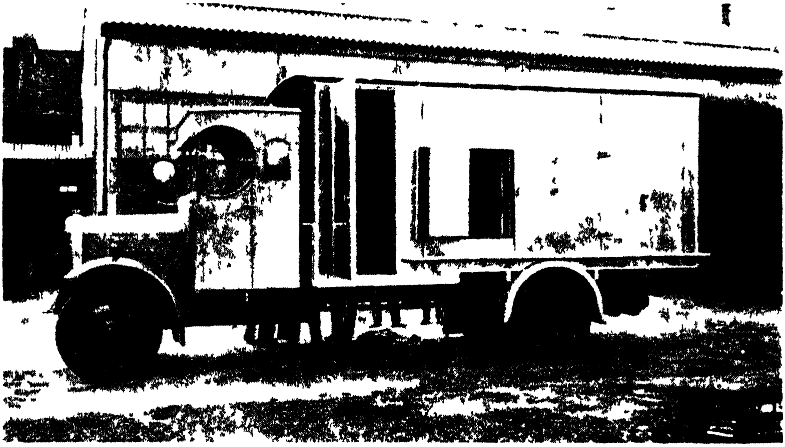

FIG 166

The methyl chloride compressor is driven by belt from a small water-cooled petrol engine, which obtains its supply of cooling water from the radiator for the lorry engine.

Starting and stopping are controlled by thermostat in the van body, the electric current being obtained from the lorry batteries

The condenser is air-cooled and the insulated space is cooled by flat cooling plates fitted on the walls and ceilings, and protected by grids to prevent damage that might be caused by movement of the load.

§ 16. Silk—Artificial

There are several processes used for the manufacture of artificial silk, and while all require refrigeration, the temperatures used and power required vary considerably in the different factories.

The raw material is either a cotton pulp, a wood pulp, or a mixture of the two, and the first step is the conversion of the pulp into an alkali cellulose. This is performed by steeping it in a solution of caustic soda, very cold water being occasionally required, after which the pulp is pressed to remove the free soda, and then disintegrated. The cellulose is then mixed with carbon bisulphide in vessels known as churns. During this process a gelatinous cellulose xanthate is made, which is insoluble in water, but soluble in dilute caustic soda. By dissolving it in this latter, the actual viscose solution is obtained, from which the thread is eventually made. At this stage all the original structural fibre has disappeared

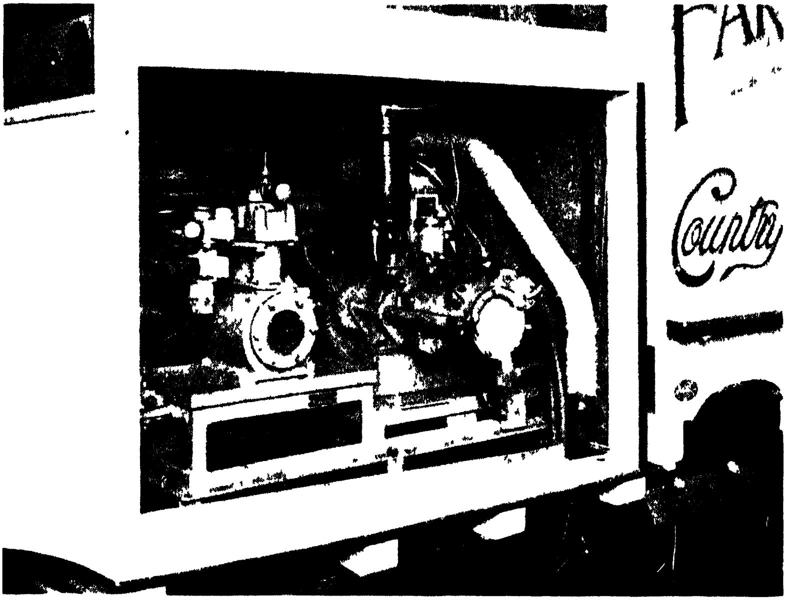

FIG. 167

The viscose fluid then passes into vessels, where it remains for a ripening process.

During this stage the xanthate gives off some of the carbon bisulphide, and becomes the cellulose solution or ripened viscose.

The churns and ripening vessels are either constructed with jackets, through which cold brine, generally at a temperature of 24° F., is circulated, or they are placed in insulated rooms cooled to a temperature of about 40° F.

For these duties a considerable refrigerating power is required; the average amount varies but may be expressed as being approximately 1000 B.T.U.s per hour per each hand employed, and the refrigerating plant must work continuously.

The ripened viscose is then taken to the jets of the spinning machines, which consisit of platinum caps bored with a number of very fine holes. The filaments from these are passed through a setting solution, and are then spun on a rapidly revolving mandril or wheel into the fine silk-like threads, refrigeration occasionally being also used at this stage.

§17. Skating Rinks

For curling a length of 140 ft. should be provided, and the width required for each rink is 16 ft. About 80 to 100 ft. is the minimum for ice hockey, and in figure skating some figures require about 80 sq. ft. These considerations fix the minimum size of a real ice skating rink at about 140 by 80 ft. The various rinks which have been constructed have floor areas varying from 14,000 to about 24,000 sq. ft.

The floor proper is constructed as a shallow pond with piping laid at close centres and encased in the concrete floor. By circulating cold brine through the piping, the water is frozen solid and forms the necessary ice surface. The piping usually employed is 1¼ in. in diameter. It is placed at 4 to 4½ in. centres and is made up in the form of coils for the full length of the floor, as illustrated in Fig. 168, showing an ice skating rink floor in course of construction before the concrete, which encases the pipes, was laid. The various coils are connected and valved to the main brine inlet and outlet headers. The ice is formed to a thickness of about 1 in or slightly more, and in

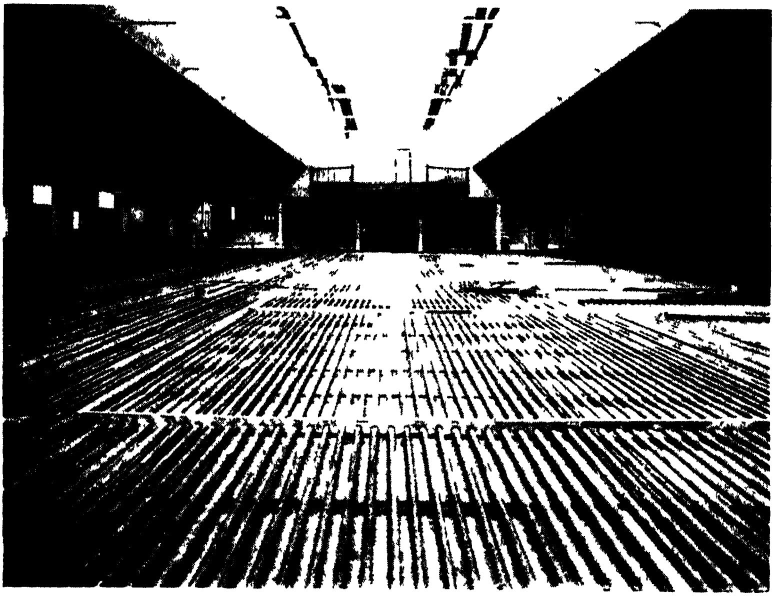

FIG 168 ICE SKATING RINK FLOOR

use it is, of course, necessary to frequently scrape and re-surface the ice, the re-surfacing being effected by spraying on water which, of course, immediately freezes

In the course of a season the ice tends to build up to a rather greater thickness, it to some extent becomes crystalline and calls for greater refrigerating power. The actual refrigerating power required naturally varies with the temperature, and also to some extent with the number of the people using the floor. It is usual to provide two refrigerating machines, one of which will meet normal requirements, the other serving as a standby, while both give a margin of capacity to meet any exceptional conditions. When two compressor units are installed, each should have about one ton refrigerating power for each 250 to 280 sq ft of ice surface. If a single machine is to be provided it would appear advisable to give it a greater margin of capacity.

The skating season on an ice rink generally extends from early autumn until the end of spring, but there are some rinks which are kept open through the whole of the year.

§ 18. Miscellaneous Applications

Horticulture. Refrigeration is used to retard the development of bulbs so that they may be brought into flower at any period. Cold storage is practically a necessity for the growers of the lillies, the bulbs of which are imported from Japan, and many of the larger growers have their own cold storage plant.

The process of retardation is also used to some extent in connection with the bulbs of the lily of the valley to provide an all round supply of this flower.

The cold stores for bulbs can follow any ordinary lines, and cooling may either be by means of direct expansion by brine piping or cold air circulation. The temperature required is about 35° F. and the bulbs should on no account be frozen hard.

Wine. In the manufacture of some varieties of wine the filtration is best carried out at a low temperature. Refrigerating machinery is used for cooling the liquid and, in this and some other similar cases, an interchanger can be used to reduce the size of and power required by the refrigerating plant, the outgoing cold wine serving to cool down the ingoing warm liquid, and being itself warmed up towards a normal temperature in the process.

During the last few years there has been a great development of the process of treating wine by refrigeration in France and Algeria, and there are many large establishments in these countries where the buildings consist entirely of ferro-concrete vats, lined in some cases with glass tiles, and in others with a special composition that gives a jointless finish. Some of these vats are used for blending; some are specially insulated and arranged for storage at a low temperature, while others are used for storage at normal temperatures. They are all

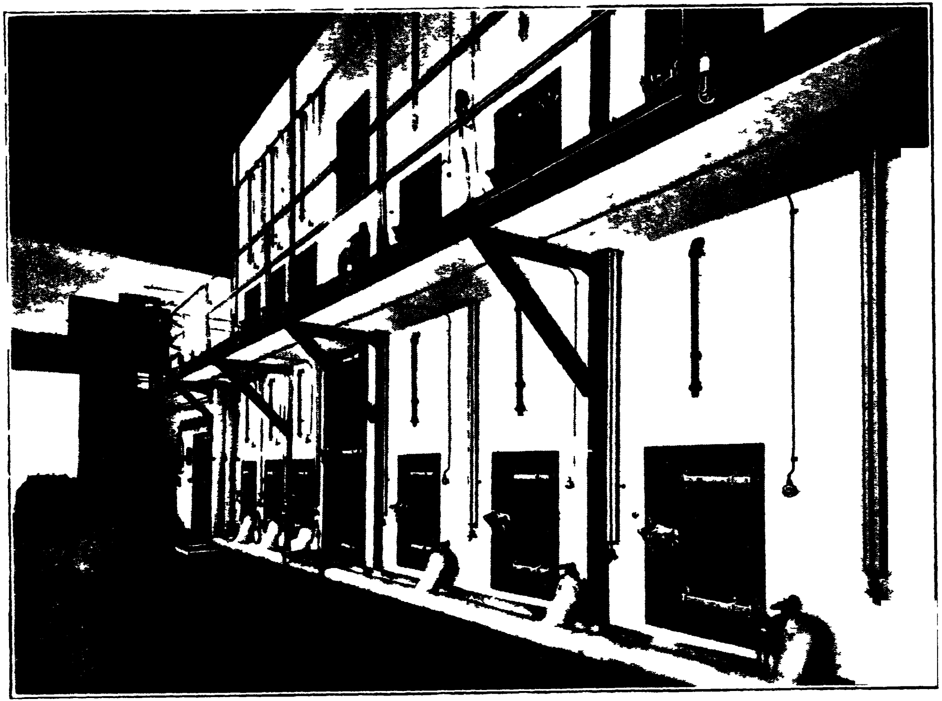

FIG. 169

arranged in conjunction with a refrigerating and filtering plant, and are connected up accordingly.

With the rapid growth of the trade in Empire wines, this process of treatment by refrigeration has been applied with great advantage to the quality and stability of the wine, and installations designed by the author are now in operation in this country, and in Australia and in Canada.

Fig. 169 illustrates insulated and refrigerated vats having a capacity of about 40,000 gallons and forming a portion of one of these installations.

Bakeries. Refrigerating machinery has been used in bakeries for cooling the dough in the larger sized modern high speed mixers, where the heat generated cannot be effectively carried away by means of ordinary water jackets. The cooling has, in some cases, been carried out by circulating cold brine through the jackets, but it appears probable that the best method is to inject cold air into the dough through orifices in the mixer. The partial oxidization effected in this way helps improve the quality and turns out a whiter bread.

Refrigeration has also been employed in hot weather and hot climates in air conditioning for the dough rooms, so that the process of fermentation which takes place there can be effectively controlled.

Silk Worms. Silk worms are largely cultivated in the East. An early spell of warm weather may, on occasions, induce the grubs to emerge from their eggs before the risks of fatal frosts is over, or before the proper development of the foliage which constitutes their food. When this occurs it may involve considerable losses. A remedy is the use of refrigeration, and it has been successfully applied to prevent the too early hatching of the silk worm eggs.

Sundry Uses. In the process of making, lenses are ground in a matrix or mould of pitch. After grinding, the usual means of removing the lenses from this mould is by tapping it. This, however, is liable to result in a number of lenses being spoiled owing to chipped edges. To avoid this the lens, together with its mould of pitch, are in some cases dipped into a bowl of cold brine, the difference in the rates of contraction quickly frees the lens from its mould without any damage or difficulty.

In photographic and film works refrigeration is used to control the temperatures used in the coating rooms, and frequently also to cool the emulsions themselves.

In chemical and pharmaceutical works refrigeration is employed for a number of processes. Instead of applying cold brine or the direct expansion of evaporation of the refrigerant, an ice-making plant is often installed, and the process of cooling is carried out by means of ice, either as a cooling medium or by the method of direct contact and mixture.

In the electrolytic bleaching apparatus, the temperature of the electrolyte should not be allowed to exceed about 80° F. Heat is always generated in the process, and in ordinary climates the cooling can be effected by ordinary water circulation. In hot climates, however, such as India, this is not possible and a refrigerating plant must, therefore, be used for the purpose.

Refrigerating machinery has been used also for removing the heat generated in electric storage batteries in the process of forming.

Refrigeration is employed in the manufacture of colours and of dyes, for the setting of gelatine and of boot polishes, and in a number of other industries, in fact, it is hardly practicable to make a complete list of all the uses to which refrigeration is applied, as they are constantly extending. In some cases the processes are the jealously guarded secrets of the owners and in others, such as in the reported case of the sick Polar bear who was put into a cold store with an immediate improvement to his health, the application has been so rare as hardly to call for notice.

CHAPTER XIV

THE DESIGN OF ABATTOIRS, FREEZING AND MEAT PACKING WORKS

METHODS of killing animals for food, dressing the carcasses, and dealing with the meat and by-products have reached a high state of perfection in those countries where meat is killed for export, and in those cities like Chicago, where animals are killed in central packing houses and the meat railed to New York—over 1,000 miles away—and to the markets of other towns and cities. Several excellent books have been published in the United States dealing particularly with packing house design and practice, but, so far as the author is aware, no work has been published which deals with the design of an up-to-date abattoir, such as ought to be built by a municipality for killing and preparing the meat sold by the butchers in the town or city it controls. In all these matters refrigeration must of necessity play an important part, and though it may appear out of place in a book dealing primarily with mechanical refrigeration to devote much space to those aspects of animal slaughter which do not actually call for its use, yet the subject is so little understood in this country, and the necessity for education is so great, that dispensation is sought on this score. The following remarks, though necessarily incomplete, may help towards a better understanding of the problem.

Generally speaking, abattoirs should follow the same principles of design as meat works, the essential difference being that, in abattoirs, killing is generally done in detail, while in freezing and meat packing works it is done on the principles of mass production. In the British Isles abattoir practice has been terribly behind the times, and until the opening of the Sheffield abattoir in 1929 and the Liverpool abattoir in 1931, the best examples of municipal abattoirs were to be found in Australia and New Zealand. Private slaughter houses are the rule rather than the exception, and the methods of killing are crude in the extreme. In the older abattoirs and slaughter houses the bullock, etc., to be killed is caught in the adjoining pen—or the animals are tethered in the slaughter house itself—a rope or chain is put round the horns or head, the other end of this rope passes through an iron ring in the floor or wall, and is sometimes attached to a winch or windlass. For dairy cows and hand-reared animals, which have been brought up to trust mankind, the winch is not necessary; for wilder animals it is, and there is great danger to the men in man-handling a beast, especially Welsh or Scotch animals, under these circumstances. Canadian cattle, now imported in large numbers, will not submit to roping or tying, and their struggles result in bruised beef and broken aitch bones. When the winch is worked the animal is drawn along by force to the ring in the floor. The beast naturally strains every muscle to hold back, but the winch on the other side of the wall is too strong, and the animal slips along the floor towards the ring, sometimes, if reluctant, urged forward by shoving, tail-twisting, or other cruelties. When its head is drawn so close to the ring that it cannot move it, it is either poleaxed, or a mechanical killer pistol is put on to its head and it is shot. The throat is then cut and the animal bled. In the best existing establishments the carcass is drawn into another room, where it is dressed.

Sheep and pigs are stuck, the latter being sometimes stunned. The edible fats and offals remain the property of the butcher, and those he does not want are generally sold to an allied trade, whilst the inedible portions are disposed of in the same way. In some cases the animal, whilst being drawn to the slaughter ring has, by some means or other, escaped. It has then to be re-caught, or in the case of dangerous beasts—and under these conditions beasts can be dangerous—dispatched by some other means. In one case the animal was ham strung and then poleaxed whilst lying helpless on the ground. In any case, imagine for one minute the state of terror and fever flush of the animal whilst it is being badly man-handled, and forcibly drawn up to the slaughter ring, and it is in getting the unfortunate animal into a position in which it can be poleaxed, stunned with a mechanical instrument, or koshered, that the cruelty occurs, blood fevers are generated, and the meat is damaged, both from deterioration within and physical damage without. In the private slaughter house or public slaughter hall, as at present designed, the very valuable by-products are not realized to the best advantage, and sanitary and veterinary science are not given full scope to exercise their protective proclivities to the advantage of the meat consumer.

These conditions of slaughter were world-wide, and probably would have remained standard practice all over the world, as they are in England to-day, had it not been for the introduction of mechanical refrigeration, which made it possible to freeze or chill beef and freeze mutton, and transport it long distances whilst in this state. The first killing in the oversea freezing works was done by the methods just described. It was held that if an animal had to die, the sooner it did so the better, and stock which had probably been driven many miles, and had arrived at the yards in a hot and exhausted condition, was slaughtered on arrival.

It was found that, for some reason or other, the meat was bad, would not keep, and when it arrived in the English market and was thawed out, it was unsaleable. This condition of affairs, if allowed to continue, would have meant ruin to the freezing works, and careful investigations were undertaken to ascertain the cause of so disastrous and mysterious a state of affairs. Ultimately, it was found—at that time by experiment—as the science of blood enzymes had not been developed—that if the stock were allowed to rest at the freezing works for some days, and were given time to recover from the fatigue and excitements of their journey, the meat was in better condition. From this it was deduced that excitement was deleterious, and the matter was carried forward stage by stage and step by step until the animals, after being fed and rested, were stunned in special pens and killed before they had any idea that anything extraordinary was occurring.

The different steps which were taken before this state of affairs was reached echoed and re-echoed all along the line. It made the stock grower careful in the handling and driving of his stock, but above all it made the proprietor of the freezing works very carefully consider his stock, from the time the living animal entered his yards to the time the last component part left the freezing works, either as meat, hide, oleo, tallow, meat extract, meat meal, poultry food, or manure. The freezing works led the way, and when the growing population of the various cities called for public abattoirs, the men who had designed the freezing works were ultimately called in to design the abattoirs, and so the perfect abattoir came into being.

It must be remembered that killing and dressing meat is merely a factory process reversed. In the ordinary factory the raw material is brought from many parts of the world, fabricated in the factory, and sent out as a finished article. In an abattoir or meat works the complete animal is the raw material, but instead of a system of building up there is a system of dismemberment, and the animal is, so to speak, resolved into its component parts. Now each of these component parts is of value, and it is in getting the last farthing of value out of them that successful abattoir design consists. It is not of the slightest use thinking of abattoirs in terms of bricks and mortar as one might of an ordinary building. The secret lies in the details, and only those who have had packing house experience can tell what these details ought to be, and in what part of the process they should be placed.

Fig. 170 is a bird's-eye view of the abattoir at Homebush Bay, Sydney, N.S.W. It is the property of the Metropolitan Meat Industry Board, and is the public abattoir for the city of Sydney, and the centre of a very large meat export industry. The inception and construction of this abattoir are looked upon in the meat world as an object lesson of what not to do. The circumstances connected with it are, happily, somewhat unique, because as a rule people who have money, especially public money, to spend, take care to place the work in qualified hands. There has been over here recently one well-known example of the folly of neglecting this rule, and it is to be hoped that the lessons will sink home in both hemispheres. *The Pastoral Review* in 1919 tells the story—

> The trouble in the early days of the conception of the new scheme was that, although there was a general recognition of the necessity

for an improvement upon the antiquated Glebe Island methods and buildings, there was apparently no one connected with the scheme who was possessed of the requisite technical knowledge of such work. The result was that architects, draughtsmen, and engineers, all in their own individual, and, to an extent, independent way, designed buildings and plant which may or may not have been triumphs of designing skill, but were not of much value for the actual work of the future undertaking. During the many years that the undertaking was in course of construction there was never connected with it a controlling expert versed in the numerous requirements of a modern abattoir. The early plans were defective by reason of the designing being in the hands of those who knew very little about the construction of such an establishment. When at last outside criticism of the grave mistakes that were being made was indulged in, the Government of the day awoke to the fact that there was something radically wrong in the execution of the whole scheme, and made an attempt to put things right. Unfortunately, however, the men who were appointed to do so were as inexperienced in the special designing that was necessary as their predecessors, and the result was further errors involving the expenditure of hundreds of thousands of pounds without improving the position. There followed a series of building, pulling down, re-designing and re-building, and still without approaching very closely to the objective of a really up-to-date abattoir. There were certainly some sections of the scheme worked out with considerable skill, and

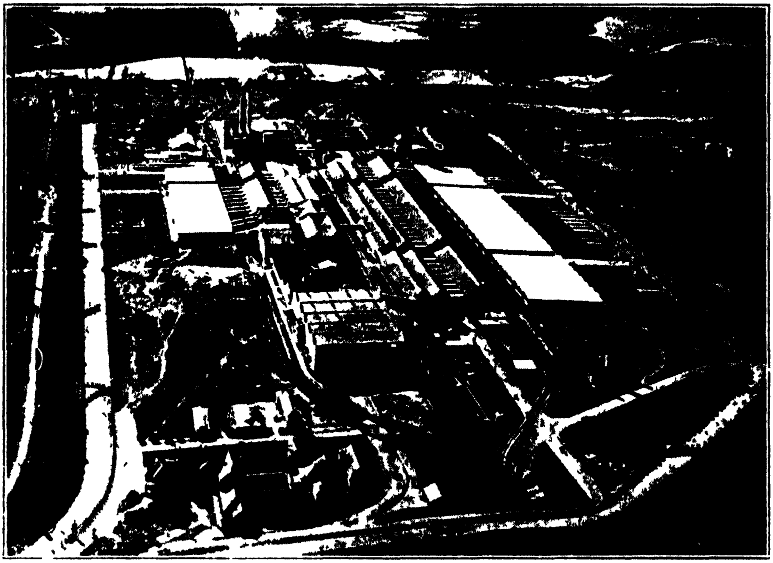
FIG. 170

many of the buildings are, from an architect's and builder's standpoint, deserving of special mention, but since they have not very well fitted in with the general principles of a broad scheme of abattoir construction, their value is considerably minimized. When at last the Government became fully conscious of the problems involved in the work of designing and establishment of this magnitude, further efforts were made to remedy the defects that had been made in the early and subsequent stages of construction. To an extent these efforts produced good results, but it became evident to the Government that the appointment of someone possessed of special qualifications to supervise the undertaking even at this late date was an imperative necessity.

Ultimately, the abattoir was taken over by the present Board, who largely re-built it; wrote off £700,000 as wasted capital; and, to quote *The Imperial Food Journal,* "within the space of a few years has changed what was a 'white elephant' of a growingly objectionable character into a State asset that has exacted the admiration of the world's meat experts."

It will be noticed that the abattoir is double: cattle and calves on the right, and sheep, lambs, and pigs on the left. The open stock pens are on the two outer sides. Next come the covered pens to rest the animals and protect them from the weather; then the bridges leading to the individual slaughter pens, each with its meat dressing floor, hanging rooms, and chill rooms. From the latter the meat is dispatched to the city for consumption. The abattoir is intersected by three double railway tracks and two roads, whilst two other roads form its boundaries. Stock is delivered by rail or road.

A feature of the abattoir shown in Fig. 171 is that it consists of two floors. This construction is common to all modern overseas works, but was unknown in this country before the opening of the Sheffield abattoir. The killing and dressing is done on the upper floor, whilst the whole of the offal is delivered through chutes to the floor below and is treated there, the inedible portions going direct to the digester house, where they are dealt with in a sanitary manner and turned into saleable products. The revenue of the Board is derived from various sources: (1) the collection of fees or dues for services rendered, the sale of by-products, sale of animal and poultry foods; and (2) the rentals derived from special buildings which have been erected for operators, such as meat canners. In 1921 the Board was able to report that, after paying to the Government the sum of £45,000 as interest on capital cost, there remained a balance of approximately £60,000 as excess of revenue over expenditure.

Fig. 172 is a bird's eye view of the municipal abattoirs and stock markets at Adelaide. These were called into being under the Metropolitan Abattoir Act of 1908, and were initiated and carried to a successful conclusion by the City Council of Adelaide, the main object being to secure a pure meat supply Its various Acts of Parliament give the Board an absolute monopoly of the slaughtering of stock within its area. Under these conditions the scheme had to be a very comprehensive one, and includes the slaughtering of cattle, sheep, lambs, pigs, and calves, cold storage and chilling chambers, the manufacturing of by-products, such as beef dripping, mutton dripping, mutton and beef tallow, lard, mixed tallow, blood manure, bone dust, bone manure, and chicken food. The Board also delivers the carcass meat direct to the butchers'

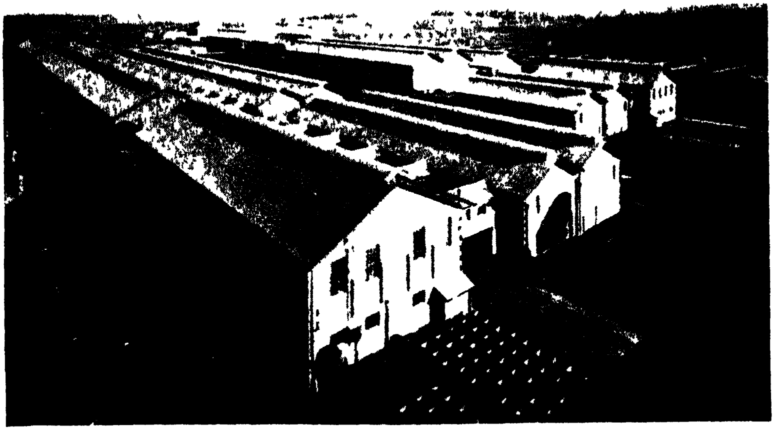

FIG. 171

shops at a flat rate, wherever they may be situated within the Board's area. The animals are, of course, killed in the most modern and hygienic premises, and under the most scientific conditions. Ante and post-mortem examinations are carried out by a trained staff of inspectors at the head of which is a qualified veterinary surgeon. The Board undertakes the slaughtering of stock and delivery of the carcass meat to the butchers' shops at the direct request of the master butchers of the area, who, at their own desire, ceased to be butchers and became meat purveyors. Over 150 tons of meat are delivered to the shops on a busy day, and the annual revenue is over £200,000.

FIG. 172

The Adelaide abattoir is a paying concern. A description of it and of its method of working was given by the author in a lecture at the Royal Society of Arts in 1923. He referred to it again in the paper he read to the two Associations of Market Authorities in 1929 It is not, therefore, necessary to repeat it here.

It is, however, interesting to note that in 1928, before proceeding with their abattoir which has just been opened, the Queensland Government appointed a Commission to inquire into the meat industry generally, and the Commission reported: "We are of opinion that, while slaughter yards have generally complied with the regulations governing their operations, their limitations render them unsuitable for the requirements of large cities and towns, where they should be superseded by a centralized killing establishment, and chilling facilities for all meat prepared for domestic consumption

FIG. 173

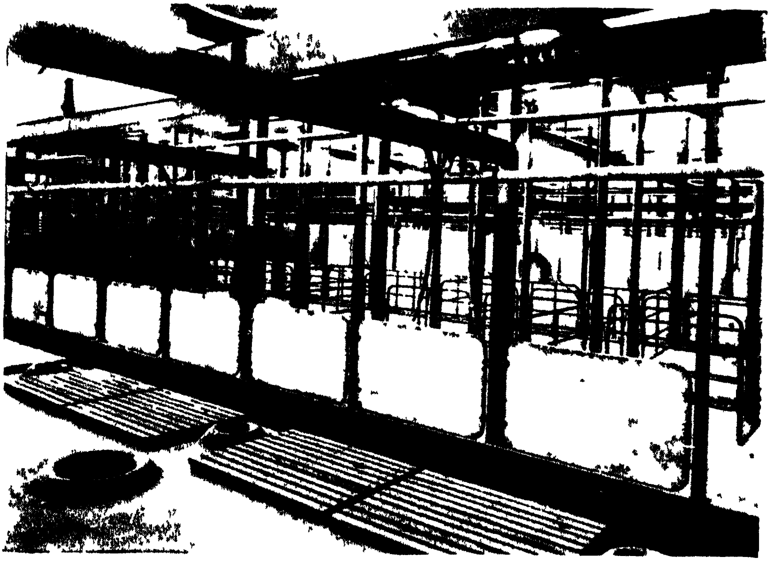

FIG. 174

"The technical evidence on the question of domestic killing is that a centralized system is necessary for the proper inspection of meat products for home consumption, and that all meat should be properly chilled immediately after slaughter.

"Two different operative systems are followed in Australian abattoirs, one termed the collective system, the other usually referred to as the pen system.

"Under the collective system, as adopted by the Adelaide abattoir, the management controls all operations. The killing and other processes are carried out by the Board's employees on behalf of the operators.

"The pen system, as used at the Sydney abattoir, provides separate killing floors and chilling rooms for each operator, or group of operators, who provide and control their own labour.

"The controlling authorities of both abattoirs referred to consider that, for several reasons, the collective system is much the better. It calls for less capital expenditure in buildings and plant, is more economically operated, and enables one standard of work to be adopted under the supervision of one management."

The report concluded: "We carefully investigated the merits of both systems and unhesitatingly recommend the adoption of the collective system," while the Chief Veterinary Officer for the Commonwealth (Meat Export) Branch added: "To my mind the Adelaide system is the one for efficiency. It is by far the cheapest and most economical system."

Fig. 173 is a view in one of the slaughter houses and shows the stunning pens, one with the door raised, the other with the door in the position in which it is when the animal to be killed enters the pen, is stunned, and rolls out on to the floor of the slaughter house.

Fig. 174 illustrates the sheep slaughter bank, and shows the openings of two offal chutes leading to the floor below. Fig. 175 shows the other end of the chutes in the offal department, where the offal is prepared. Figs. 176 and 177 are borrowed from Messrs. Wilder and Davis's excellent book, *The Modern Packing House,** and illustrate the method of stunning

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* Nickerson & Collins Co., Chicago.

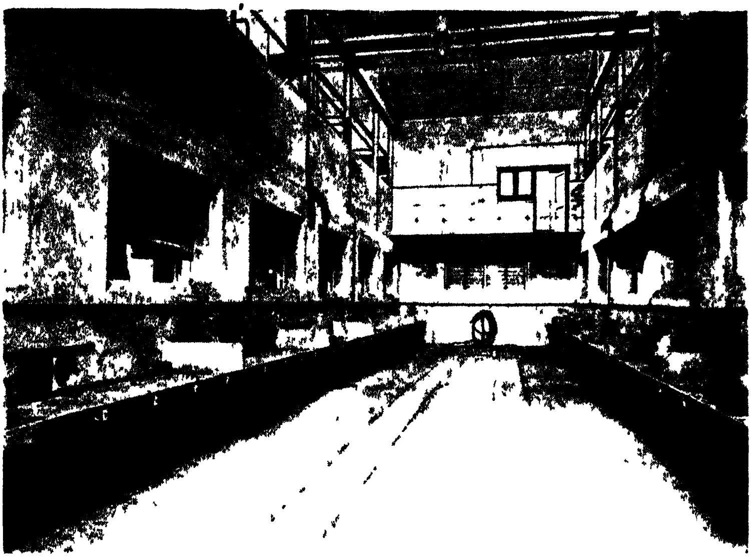


Fig. 175

Fig. 176

cattle with a 4 lb. hammer. This is the system used in North and South America, as well as in Australia and New Zealand. The former shows the striker in the act of striking; whilst the latter shows the stunned beasts which have rolled out on the floor, about to be hoisted for sticking, heading, etc. The next two figures 178 and 179 show an automatic stunning pen, the invention of an Australian engineer. The photographs are crude and are reproduced merely to illustrate the principle of the stunning pen. The former shows the animal in the pen with his head held high, trying, though ineffectually, to see out of curiosity what is going on. The striker stands on the platform immediately behind the animal's head. The latter photograph shows the stunned animal automatically

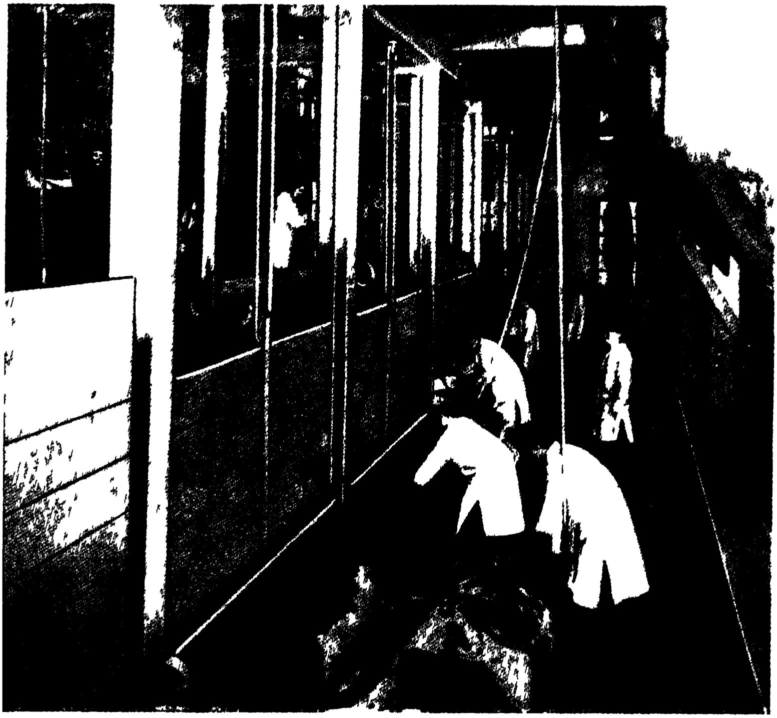


FIG 177

tipped out of the pen and lying on the floor after it has been struck.

In an old country like this custom dies hard, but it is now

FIG. 178

becoming realized that the system of centralized control of all killing, as practised at Adelaide, has many advantages. In the author's opinion it is the ideal system, and something like it is bound to come sooner or later, primarily as a measure of public health, but also as a matter of national economy.

In London, most butchers buy their supplies of killed and dressed meat at Smithfield Market. They are, in fact, meat purveyors, just like the butchers in Adelaide, and they would not revert to being slaughter house owners if they could.

All animals should be inspected before slaughter, and immediately after slaughter there should be a thorough inspection of all meat by competent veterinary officers.

FIG 179

The Public Health (Meat) Regulations, 1924, Part II, Art. 7 (2), lays it down that Arts. 8, 9, 10, and 11 of these Regulations shall not apply where the slaughter takes place in a slaughter house under the management of the local authority. This means that notice of intended slaughter, notice of disease found after slaughter in the carcasses or internal organs, and detention of the carcasses and offals for three hours after slaughter, need not be carried out by the butchers.

This, in effect, means that local authorities are obliged to employ a sufficient meat inspection staff to carry out meat inspection if the slaughter of animals is concentrated in an abattoir under their control, unless they are content to place the onus of selling unsound meat in the shops on the butchers, and carry out shop inspection with seizure under Art. 116 of the Public Health Act, 1875.

The inspection of meat killed in a slaughter house under the management of the local authority, however rigidly carried out, can only be a safeguard to the inhabitants in its area if fresh meat, slaughtered and dressed in private slaughter houses and farms outside its area, is also subject to the same inspection. This can only be done by passing suitable by-laws making it compulsory for all vendors of meat from outside areas to bring this meat to the public slaughter house, where it would be inspected by the staff employed to inspect meat slaughtered therein. The slaughter house would thus act as a clearing house for all fresh meat killed and dressed outside the area and imported into it, and would ensure that nothing but sound, fresh meat was sold in the area of the local authority.

The inspection of meat killed and dressed in a number of private slaughter houses in the area of a local authority is very unsatisfactory for several reasons—

(*a*) It involves the use of a large staff of inspectors, some of whom may not have sufficient experience to enable them to detect incipient disease.

(*b*) A large staff of this nature is very expensive.

(*c*) The absence of an inspector when the carcass is opened up gives the butcher an opportunity, should he so desire, of oblitering disease by substituting the organs of a sound animal for those of the carcass to be inspected.

(*d*) The permission granted to butchers for the removal of meat three hours after slaughter if, in the meantime, it has not been inspected, opens the door to possible fraud in the time of notification and to "misunderstandings."

(*e*) With private slaughter houses successful and thorough meat inspection is far too dependent on the honesty and goodwill of the butcher and on his retaining all the carcasses and their offals for inspection before their removal for sale.

(*f*) Inspection at a central slaughter house is greatly facilitated by a detention room in which any meat suspected of incipient disease can be retained while investigations are being carried out in the laboratory. With private slaughter houses this is not practicable, and, consequently, much meat which would probably have been condemned at a central slaughter house, passes into consumption from the private slaughter house.

After the concentration of slaughter and the closing of the private slaughter houses in Sheffield, the ability to inspect all the animals, carcasses, and offals immediately before and during the process of slaughter, caused an increase in the amount of meat condemned of almost 80 per cent. This in spite of the fact that the meat inspection was under the control of the Chief Veterinary Inspector, assisted by a staff of Meat Inspectors prior to, as well as after, the concentration of slaughter at the abattoir.

The concentration of slaughter in a central abattoir ensures uniformity of inspection for large areas. It will thus be realized that the preparation, though not the retailing, of meat is really a public utility health service, and there is no logical reason why a municipality or other public body who supplies water, electricity, gas, a tramway service, and a sewerage system, should not also perform the killing and dressing of the animals for the butchers who have bought them.

Very few of the existing slaughter houses which have been provided by local authorities are either modern, sanitary, or efficient. The bulk of them have been designed by men who do not understand the requirements of the business, and they are nothing more than a number of private slaughter houses grouped together. Very few possess a properly equipped laboratory or suitable facilities for meat inspection. There is, in fact, no doubt that a very wide gulf exists between these premises and private slaughter houses, on the one hand, and those Dominion institutions which have been described, on the other. There is also little doubt that if the general public had any idea of the conditions under which much of the home-killed meat is driven, laired, slaughtered, and dressed, and the risk of disease which they run in eating it, they would turn with one accord to the cleanly produced and inspected imported meat, the trade in which would receive the greatest fillip it has ever had.

The present system is not fair to the butchering trade, some members of which are trying their best under difficult circumstances. It is most distinctly unfair to the farmer who grows beautiful meat only to run the risk of having it spoiled and its value depreciated by unskilled handling in unsuitable premises; it is hard luck on the people who buy and eat the meat, and it is, most of all, unfair to the animals which are slaughtered. There is a very strong feeling that the appalling conditions which have so frequently been described have lasted quite long enough, and that something very much better should be provided.

Whenever a public abattoir is proposed one of the first objections raised is that it will be a burden on the rates. So, too, are the sewers, yet what an outcry there would be at the menace to public health if the sewage was allowed to flow down the streets.

The magnificence and extent of the Continental abattoir buildings is often commented upon, and it is also pointed out that they are able to pay their way. It is not so often shown that they are only able to pay their way because the aggregate of the charges they impose averages somewhere about three times the amounts paid in England. At the Sheffield abattoir, for example, the charge of four shillings and ninepence per head for cattle includes all the services of the establishment, with 48 hours lairage and 24 hours hanging in the refrigerated hanging room, while at the Dresden abattoir, which is often quoted as a model, the total of the charges on cattle amounts to about fourteen shillings to seventeen shillings and sixpence, depending on their size and weight.

Nor does it seem to be appreciated that the arrangements for the handling of by-products and manure in these Continental abattoirs are crude and that the large open spaces between the separated buildings involve time and labour in the movement and handling of both live stock and the products. All this makes the cost of operating greater to the owner of the animal than in a more compact design.

One of the largest items on the expenditure side of any municipal abattoir's accounts is that representing the sinking fund and interest on capital. Mere size and elaboration of buildings, therefore, only involve an unnecessary dead load on the working charges, with no corresponding gain.

In constructing a public abattoir as is generally understood to-day, provision has to be made for the custom of the trade in making upwards of half their weekly kill in one day. This means that the building is only fully occupied for the equivalent of between two and three days per week. Accommodation has also to be provided to enable large numbers of individual butchers to work simultaneously. This results in a structure that is far more extensive and costly than is justified by the total amount of work done in it.

The influences of design, and of a regular daily working on the size of an abattoir, are easily demonstrated. Thus, in the abattoir at Sheffield, a kill of about 600 cattle per week is conducted with perfect ease on eight double stands. For the same weekly kill Edinburgh has thirty double stands.

The arrangements and equipment of the Sheffield abattoir enable this number to be easily dealt with and the butchers also kill all their sheep in the same slaughter houses. The original design contemplated a separate slaughter house for sheep, but this combined arrangement was made at the special request of the butchers. It has since been altered.

There is no doubt that the home-killed meat trade in this country is carried on in an uneconomic manner. There is an appalling amount of waste and nothing like the best value is made of the by-products. This is, perhaps, inevitable when the trade is in the hands of such a very large number of small individual units.

If, as was at first intended, the Sheffield abattoir had been constructed for operation as a single unit by Corporation employees, who did all the killing, and for reasonably regular working, the eight slaughter places could have been still further reduced in number, the arrangements could have been greatly simplified, and much expense could have been saved.

It is not intended to infer that the cost bears a direct relation to the number of killing places, or that an up-to-date abattoir for the same kill as Edinburgh could be constructed at, say, one-fifth of the cost of building another abattoir of the Edinburgh pattern to-day. In order to save a great deal of money in some directions it is necessary to spend a certain amount on facilities which practically do not exist in the Edinburgh type.

On balance there is, however, a considerable economy in first cost in the single unit design. The better service provided, the bulk treatment of by-products, the reduced cost of operation with the improved facilities for management and meat inspection, would amply justify the type even if these savings did not exist.

The solution of the problem lies in the construction of a series of regional abattoirs. Each of these would be operated as a single unit and managed as a public utility corporation. The capacity of these regional abattoirs would be determined by the area and population which each could serve by motor transport. Within that limit each unit should serve as large an area as possible and the closing of all private slaughter houses within that area is an essential condition.

It is improbable that any home abattoir could be made of sufficient capacity to permit of the degree of specialization practised in the meat works of the United States or in the Frigorificos of South America. It is doubtful, indeed, whether that specialization could, or should, be practised here. The aim would be rather to adopt the practice that has been built up in Adelaide, the lay-out being improved in those ways that experience has shown to be desirable.

These regional abattoirs would be equipped with large hanging rooms where the temperature and conditions, controlled by refrigeration, would enable the undertaking to work regularly throughout the week. They would also be large enough to make the best use of the by-products, which have a much greater value if treated immediately and in bulk.

The trade has grown up to the practice of killing for the immediate market requirements. The butchers want to turn over their money as quickly as possible, but they have also had to sell their meat as soon as it was killed, because they have had no hanging spaces with controlled temperatures which would enable them to cope with the daily fluctuations in the retail demand.

The concentration of slaughter and meat inspection in a series of regional abattoirs would be of very great assistance to the development of the system of meat grading and marking now carried out under very difficult circumstances by the Board of Agriculture. The marking is at present confined to beef, but there is no reason why it should not be extended to sheep, lambs, and pigs.

This grading has so far received a somewhat mixed reception from the trade. There is no doubt, however, that it is gaining ground and that the principle of buying and selling meat strictly on its merits and of distinguishing the better qualities is obviously to the advantage of both the producer and the consumer. Only the best quality is gradable and there is no doubt that the best quality meat has more food value for the money than inferior meat at a less cost.

These regional abattoirs would not interfere with any of the opportunities that the butcher at present has of making profits by the exercise of his judgment in the purchase of his stock. A system of identification would ensure the return to him of his own meat and edible offals. He would be relieved of the trouble of slaughtering. He would receive his meat dressed in the best possible manner by really skilled men, and would obtain the best value for all his by-products. The smaller butchers, or those whose trade does not make it economical for them to deal in whole carcasses, would obtain their requirements, as at present, from the wholesale dealers and the markets.

Again, working on this scale, it would be very much easier to put into operation a system of insurance against loss to the butchers from condemnation.

There can be no necessity for every municipality or borough to have its own abattoir. Transport to the shop is necessary in any case. The risk of deterioration is in the handling at each end and in the use of unsuitable vehicles—a few miles more or less on the road is nothing. With the control contemplated, only suitable vehicles would be used for transport and meat would pass directly from the rail in the abattoir to the rail in the shop.

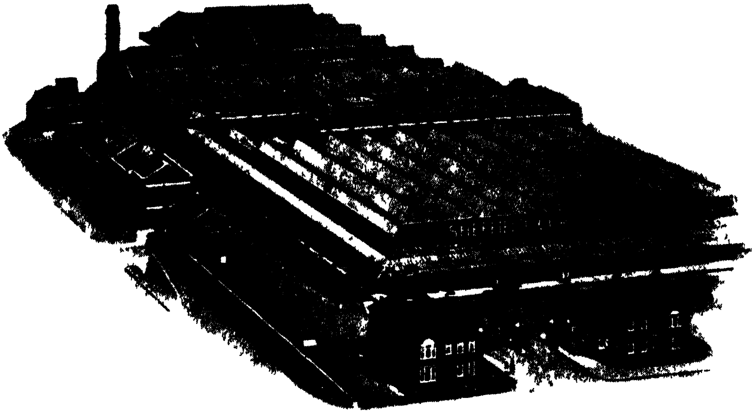


FIG. 180 ABATTOIR AND MEAT MARKET

That distance is no serious object is proved by the facts already quoted that in spite of its cartage from the abattoir to the train, the rail journey to London, and the handling it has to suffer, beef killed in Scotland fetches the highest price on the Smithfield Market.

A commencement could well be made with the most concentrated urban areas, as these present the greatest scope for economy and improved results, together with the greatest ease in distribution. There are probably few rural areas which would not come within the orbit of working radius of one of the large centres, but any such places might be served by a simplified form of abattoir from which all by-products

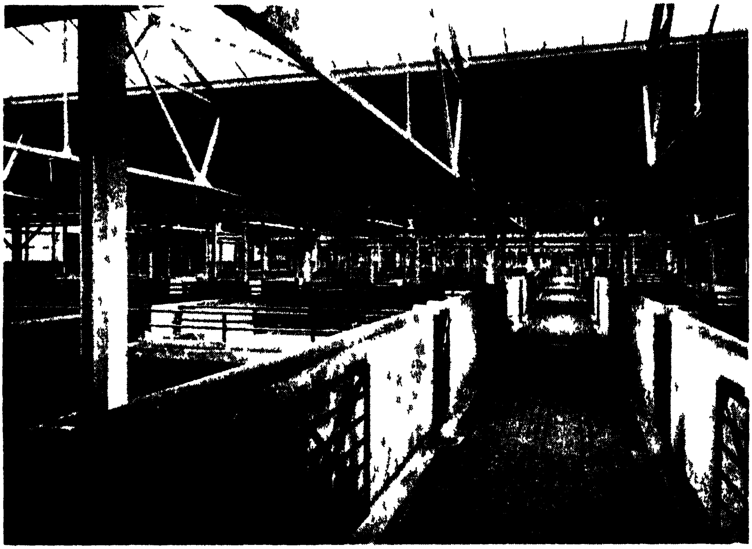


FIG 181 PORTION OF CATTLE LAIRAGE

would be removed in bulk and be dealt with in the nearest larger unit.

In June, 1929, the Abattoir and Wholesale Meat Market designed by the author for the Corporation of Sheffield, was opened by the Minister of Agriculture. It was intended to concentrate in one place the killings which had previously taken place in some old shambles and some hundred private slaughter houses scattered throughout the city. A bird's-eye view of the premises is shown in Fig. 180. The market, which is one acre in extent, is in front, the hanging rooms and slaughter houses are immediately behind, and the lairage is at the back. Stock comes in either by road or rail, and is passed directly into the lairage, a portion of which is shown in Fig 181 It will be noticed that the pens are walled so that the animals in them are protected from side draughts and are not disturbed by the droving of other animals. Gates are provided at all cross-passages to limit the movement of the stock to the way it is required to go, and to make it impossible for it to wander

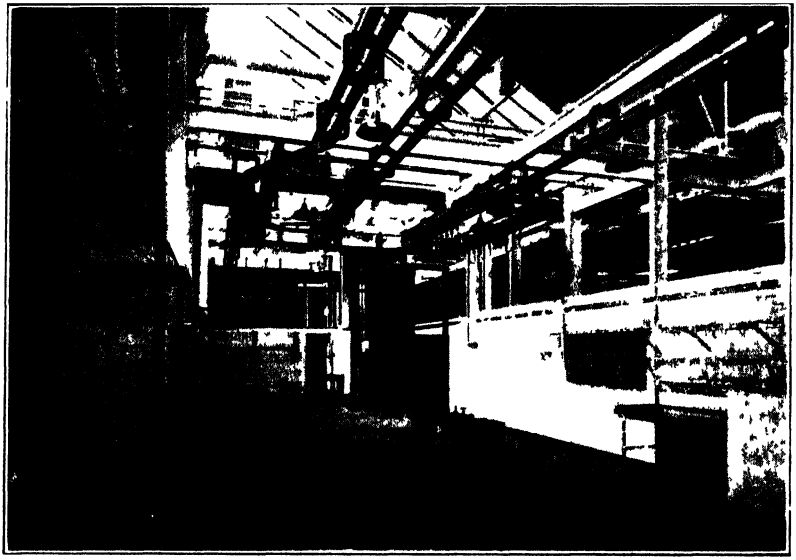


FIG 182 ONE OF THE KILLING AND DRESSING ROOMS

When required for slaughter, the animals are drafted into isolated waiting pens at the far end of the driveway shown. These pens communicate directly with the slaughter rooms by a passage which is only wide enough to take one animal at a time, and in which they cannot turn round. This passage leads the cattle separately into the stunning pen, shown black in the right-hand far corner of Fig. 182.

This stunning pen, though made throughout of steel, is in essentials similar to that illustrated in Fig. 178, page 499. After stunning, the floor of the pen tips and the animal rolls out on to the floor of the slaughter house ready for the rest of the operations The slaughter houses are double, so that two slaughter gangs can work independently

The offal rooms are immediately underneath and are in duplicate, viz.: two offal rooms to one slaughter house, thus keeping the offals of each gang separate. The mouths of three of the offal chutes can be seen under the table on the right-hand side of the illustration. There are corresponding ones on the opposite side.

Hides and pelts are sent through another chute, not shown, into a separate compartment, also in duplicate. The paunches are opened and the offals are dealt with in the offal rooms. The paunch contents are sent through a special drain to an expeller, and are delivered, in another building, in a semi-dry and odourless state ready to be sent away to the farmers. One curious fact relating to the appetites of oxen, especially cows, revealed itself in connection with these paunch contents. In order to catch any trimmings which might inadvertently pass down the drain and cause trouble in the expeller, the paunch grass was discharged on to a wire screen, and a youth was detailed to visit this screen occasionally to clear it. After the installation had been working for some little time the manager noticed a curious eagerness amongst the youths to be detailed for this duty. He found this a little difficult to understand, as ordinarily the task would not be looked upon as too pleasant a one. On inquiry, he found that it was not at all an uncommon thing for the boys to pick up money and other valuable trifles off the screen, which had got there out of the stomachs of the animals. In some weeks the takings amounted to several shillings, mostly in pennies!

The offal rooms and hide and pelt stores open out on to the corridor illustrated in Fig. 183, the offal rooms being on the left and the hide store on the right. The large pipe in the centre of the picture is for artificial ventilation. Owing to the peculiar atmospheric conditions in Sheffield the air has to be cleaned and scrubbed, and the whole premises are ventilated on the plenum system in this way.

After leaving the slaughter rooms, the carcasses are passed over automatic weighing machines and are sent to the cooled hanging rooms. In these chambers the temperature is artificially controlled, by means of refrigerating machines, to 45° F.,

FIG 183 OFFAL CORRIDOR IN BASEMENT

FIG 184 ENGINE ROOM

and the meat hangs in this temperature until it is taken into the market for sale.

The engine room, with its direct-coupled NH_3 compressor, is illustrated in Fig. 184. On the left can be seen the cooler in which the air supply to the hanging room is dealt with.

The same refrigerating machines are used to cool the cold stores which are provided under the meat market for the convenience of the firms selling imported meat.

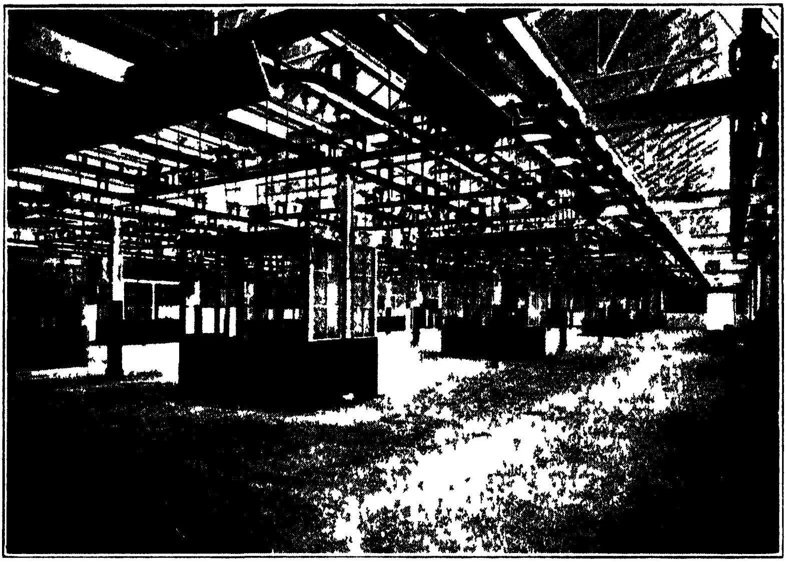


Fig 185 Portion of the Square Acre Meat Market

A portion of the wholesale meat market is illustrated in Fig. 185.

Meat should not be eaten too soon after slaughter Every butcher carrying on a high-class trade has known for generations that the palatability and tenderness of his meat has been improved by keeping, or conditioning The process has been necessary for his custom, but no organized hanging of the lower grades of meat has been practised, except in private works and in the New York Meat Market

When the author proposed to the Sheffield Corporation that their abattoir should be provided with a cooled hanging room, the butchers would have none of it, so it was suggested to the Markets Committee that some official experiments on meat conditioning would be useful. They were advised to consult Sir William Hardy on the matter, and he readily agreed to undertake a series of investigations. The results were published in the report of the Food Investigation Board of the Department of Scientific and Industrial Research and the conclusions arrived at in their report may be summarized as follows—

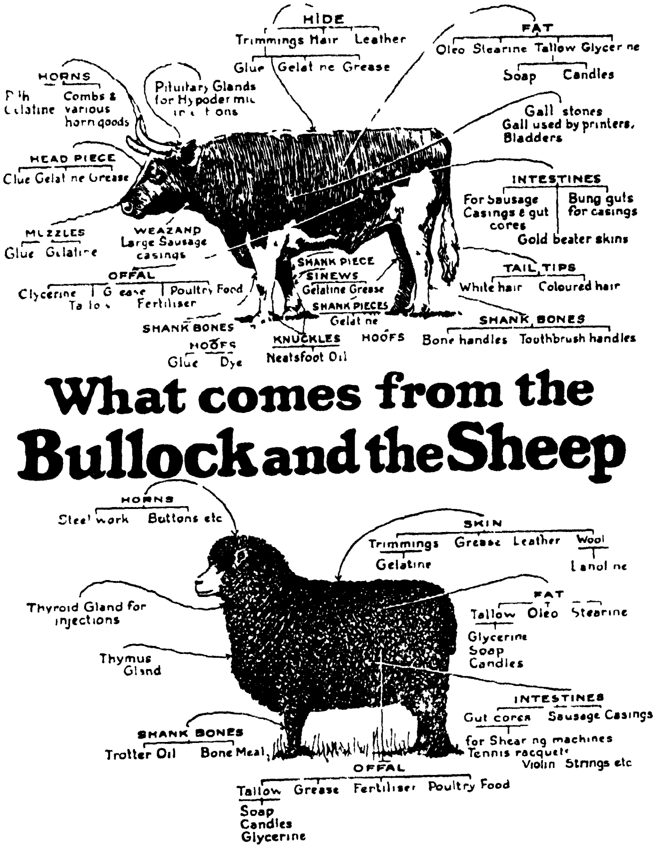
1. There is, in general, a progressive increase in the tenderness of all joints hung at 41° Fahr. (the temperature so far investigated).
2. The increase is less marked with the best quality meat—e.g. loin from prime animals.
3. There are indications that certain coarse joints and, in any case, inferior quality carcasses as a whole—e.g. aged cow beef—are greatly improved by hanging.
4. After seventeen days' hanging at 41 degrees Fahr., the meat is still perfectly sweet.

These conclusions confirmed the opinions the author had formed on the subject. They indicate that ample hanging accommodation in a controlled temperature should be provided and that it should be possible to foster the sales of the coarser meats by increasing their palatability, and, consequently, to improve the returns that can be obtained.

Unfortunately, owing to the exigencies of trade, the coarser meat cannot be kept in the hanging rooms sufficiently long for this improvement to take place, but the experiments point the way, and it is probable that with different conditions a greater use will be made of the benefits in this direction which the use of refrigeration can alone secure.

The Liverpool abattoir is, like the Sheffield abattoir, constructed to enable the individual firms of wholesale butchers and slaughtering gangs to work independently.

If there were no other reason, the regional abattoir foreshadowed in this chapter, which is operated as a single unit, could be justified by the manner in which the by-products can be utilized. Though this is not the place, nor is there space, to describe the various processes, practically every part of the animal is of value and capable of being utilized, as shown in Fig. 186.



By Products Manufactured at State Abattoirs Homebush Bay New South Wales
Prepared by Superintendent of By Products Department

FIG. 186

It is by the utilization of the by-products, usually known as offals, that the freezing works and overseas abattoirs pay their expenses. They are able to do this because it is only possible to make the best use and to obtain the greatest return from offals if they are treated immediately and in bulk.

Freezing and Meat Packing Works

The three most important elements in the design of a freezing works and meat packing works are—

1. Proximity to supplies of cattle and sheep.
2. A good water supply.
3. Facilities for distribution by rail and water.

In an export business deep water wharfage is actually more important than rail facilities. The configuration of the ground and its suitability for carrying the required buildings are also of importance in influencing the general lay-out and design and cost of construction of the buildings.

The first point is important for, as already pointed out, lengthy journeys, particularly by rail, are apt to cause serious loss in the weight and condition of stock, which had a bad influence on the quality of the meat, apart from physical damage and bruises that may be caused. The advantage of good facilities for water transport may be more than counterbalanced in this way, for instance the enormous development of Chicago as a packing centre was due in the first place to its convenient site as a centre of the cattle raising districts. While rail journeys for live stock are probably necessary, in any case they should be as short as possible, and there should be ample space at the meat works for properly resting cattle before slaughter. For rail traffic it is best to arrange separate sidings for the reception of the live cattle, and for the dispatch by rail of finished products. The former should adjoin the lairage and the latter the cold stores, or chill rooms, with covered platform accommodation, facilities for icing and, if it is desired, for pre-cooling the refrigerator vans. It may probably be found that these sidings can be conveniently arranged one on one side and the other on the other side of the main building, but their disposition will naturally depend upon the lay-out. *See* Fig. 170. There is also considerable inwards traffic in the shape of fuel and stores which should be conveniently arranged, and good road access is, of course, essential.

The lairage space must be of ample extent with proper drainage and drinking troughs. These either wholly or in part are often provided with a light roofing, to give protection from the weather in cold climates and from the sun in hot ones. In the latter they are often fitted with sprays to act as shower baths for cooling down the animals. In addition, the sprays serve the very good purpose of partially cleaning the hides. The lairage must be arranged for easy in and out handling, and its sub-division will, to some extent, depend upon the nature of the business ; thus, in a proprietary works cattle are usually graded for quality, and the lay-out of the lairage pens is considerably simpler than of a public abattoir handling separately the cattle belonging to many owners. In any case there must be adequate facilities for veterinary inspection with separate pens, and a small special slaughter house, for diseased or suspect animals. It is most important that stock should be kept in a normal frame of mind up to the time of slaughter, and that they should not be frightened or excited. This has a very important influence on the quality of the meat.

While there are certain well defined lines for the lay-out of the meat works, local conditions vary very greatly. It is seldom that all the desired features can be found. In the selection of a site, therefore, the lay-out and arrangement calls for a certain amount of compromise, with the exercise of a nice discrimination and considerable experience, in balancing up the various advantages and disadvantages. A good many of the principles necessary in the design of abattoirs apply also to meat works. In all instances the slaughter house proper is placed on the top floor. The animals are driven up a ramp or ramps to this floor, where the knocking or stunning pens which have already been described are situated. The products, as far as possible, pass by gravity to the various floors below, on which they are treated. The stunned animal falls out on to the slaughter house floor, and at no time do the waiting beasts see anything that is going on inside. The carcass is hoisted by a winch, hung on a bleeding rail, as shown in Fig. 189, where its throat is cut, and the carcass is left to drain. It is then lowered on to the dressing bed. The dressing and splitting are completed on the dressing rails, where, after weighing, the carcass passes along to the chill rooms. Weighing machines are incorporated in the rail system and should be arranged to automatically record and print a ticket for the weight of each side passing.

In favourable climates the sides are sometimes, as a preliminary, hung for some time in a well ventilated space to get rid of their animal heat. The advantages of this practice have been proved during the investigation into the freezing, storage, and transport of New Zealand meat made by the Department of Scientific and Industrial Research. Their Report (No. 41). issued recently, states that "It is inadvisable to freeze immediately after slaughter or before hanging for ten to twelve hours on the cooling floor. Groups of carcasses subject to such treatment had a definitely poorer appearance on the London markets than groups which had remained twelve to twenty-four hours on the cooling floor."

The modern American practice, however, is to run the sides straight into the first set of chill rooms, where they are cooled down to 45° F. or sometimes 40° F. It is important that the reduction in temperature should be a gradual one. In order that it may be effective, the sides should not hang too close together, and always inside to inside and outside to outside. Air circulation must be employed. From the first or preliminary coolers the sides are passed into the main cooler, which is kept while loading at the lowest temperature—say 40° F.—of the first cooler. When the cooler is full the temperature is reduced as rapidly as possible. The sides remain in it for from sixteen to twenty hours, and their temperature is reduced to 29° F. They are then ready for shipment.

Beef which is required to be sent by rail in refrigerator cars, for sale in the markets of distant towns, is reduced to a temperature of 33° to 34° F., not lower. When beef is frozen it should be first chilled, as just described, and then transferred to the freezing rooms, which are kept at or about 10° F. It remains there for about four days. Hind-quarters, particularly of heavy animals, are left in for a longer period. If the journey by rail to the ships is a long one lower temperatures are required in the freezing rooms.

The process of freezing is considered to be completed when the temperature in the thickest portions is reduced to 20° F. In Australia and New Zealand, in fact, in the bulk of British practice, air circulation in chilling rooms is generally produced by a fan and an air battery. A defect with this system is the liability of fine brine spray to pass outside the confines of the air-cooler space. Appreciable quantities of brine are in this way carried into the freezing rooms and deposited on the carcases hung near to the air delivery. This has a detrimental effect on the bloom and appearance of the frozen carcasses. It might also, in some cases, cause an unpleasant flavour in the cooked meat, but there is no definite evidence on this point. In American practice sprays with induced circulation are general. This system consists of constructing the chilling rooms with a loft, extending over their full length and width, as illustrated in Fig. 199, p. 537. It will be seen that the chill room has a false insulated ceiling with upcast and downcast spaces. The brine sprays are arranged in the loft above the false ceiling, and induce a natural circulation of the air. The warm air and vapours from the hot meat rise up the upcast, and on being cooled by contact with the cold brine, falls down through the lower opening into the rooms. Various methods of cooling are employed. In the spray system, which is illustrated, and is now general, cold brine straight from the evaporator is sprayed through nozzles which atomize it. They are generally of very similar construction to the nozzles used for cooling ponds, though with much finer outlets. The brine cools and cleans the air by direct contact, and then runs away to the evaporator to be re-cooled. The spray nozzles are so arranged that they augment the natural circulation of the air, and enable the chilling to be carried out very rapidly. The brine frequently contains impurities which are liable to stop up the fine outlets of the spray nozzles. If care is taken to prevent this the system gives very little trouble.

In the earlier designs these lofts were generally equipped with piping either for brine circulation or for the direct expansion of ammonia. As chill rooms are filled and emptied in rotation, there was no very serious difficulty in thawing off

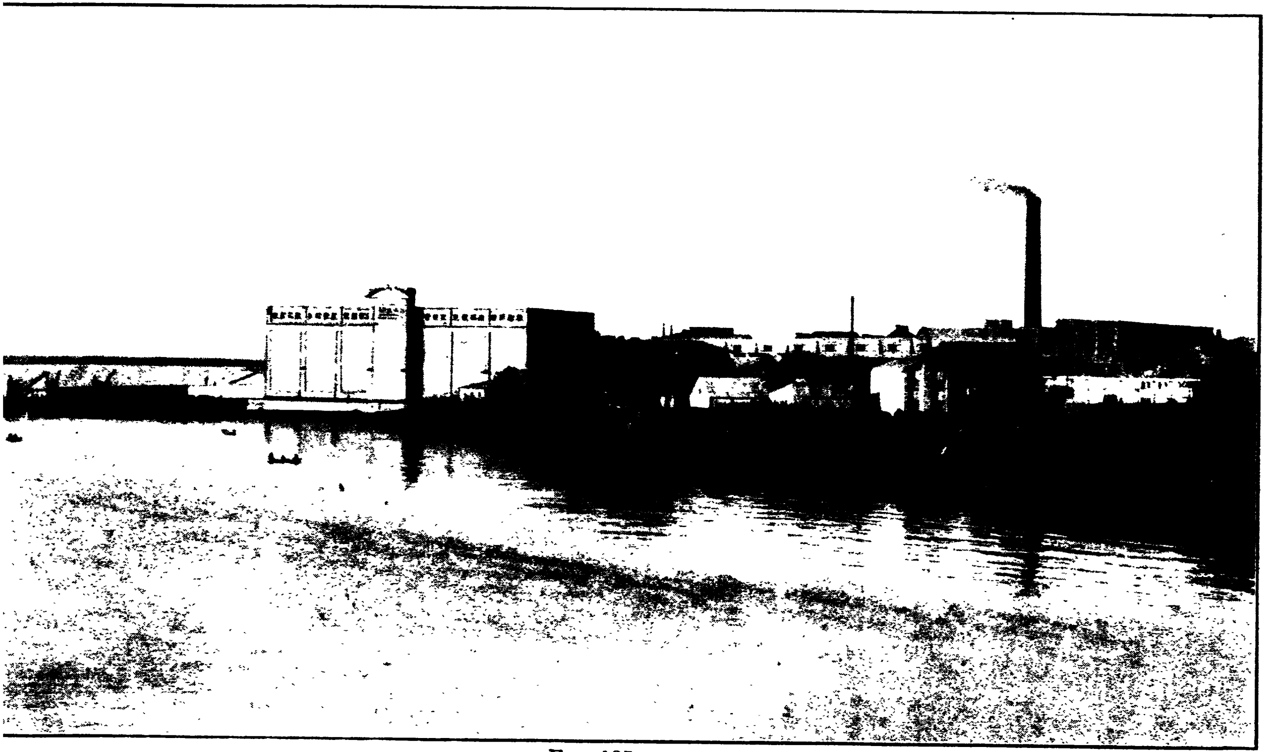


Fig. 187

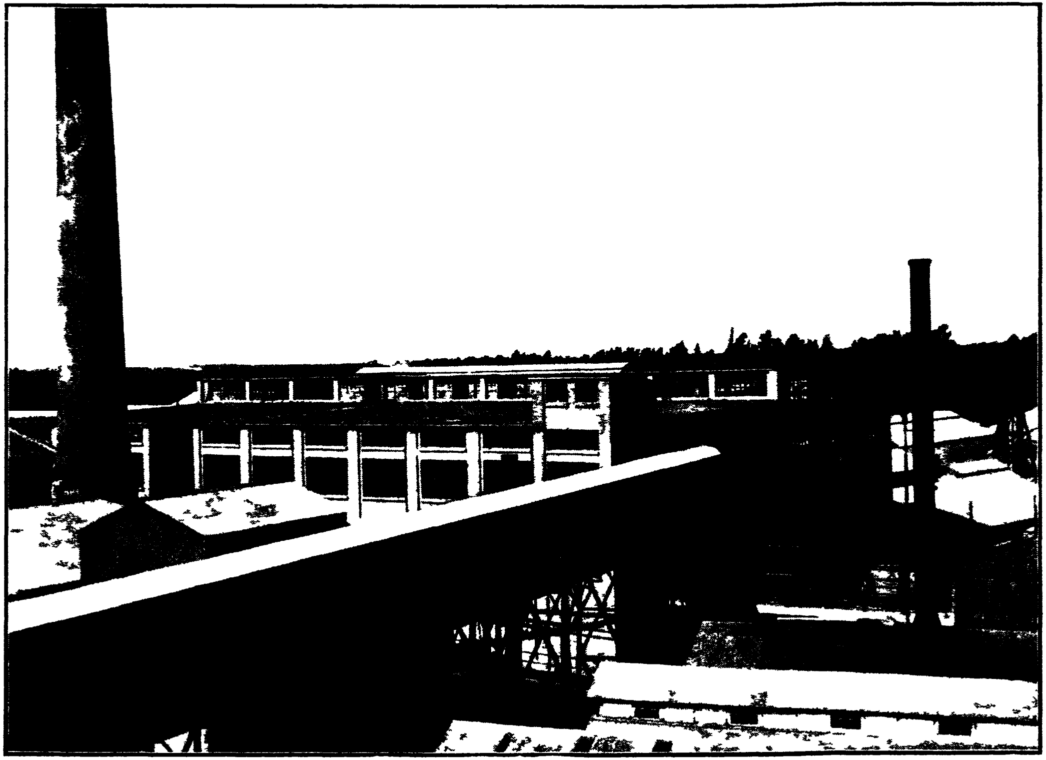


FIG 188

any accumulated snow at periods when the room was empty or relatively so. To avoid any necessity of thawing off, and also to increase the cooling efficiency of the surfaces by keeping them free from snow, the piping was often arranged with a circulation of brine over the outside like an ordinary wet cooler, and several open brine systems in which piping is dispensed with have been devised.

One of these, termed the "curtain" system, consisted in hanging in a loft a number of fabric sheets or curtains, suspended from a series of brine troughs so that their surfaces were continually wetted by the brine; the arrangement being, in effect, somewhat similar to that of the corrugated plate type of air cooler, previously described, but of course with the fabric curtains instead of corrugated iron, and with no fan circulation.

Fig. 187 illustrates the works of Liebig's Extract of Meat Co., Ltd., at Fray Bentos, Uruguay, and is a view of the factory taken from the river.

The killing building is shown on the extreme right of the illustration. It is 82 ft. by 110 ft. and 55 ft. high, containing three floors. A nearer view is shown in Fig. 188, which also shows the covered-in way, 350 ft. in length, along which the sides of beef pass on overhead rails to the chilling building, which is the large windowless structure, shown on the water's edge in Fig. 187. From this building the chilled meat is conveyed by overhead track, in a covered way to the ship's side.

The cattle reach the killing floor on the top of the building by a ramp with an easy grade. Fig. 189 is an interior view, and shows the carcasses on an endless travelling chain, which constitutes the bleeding rail. The dressing bed with the carcasses pritched up upon it is also shown. After dressing, the carcass is again hung on the travelling chain, and continues to travel until it is taken down, passing on in regular succession from process to process. This is clearly shown in Fig. 190, where the partially dressed carcasses, suspended from the runway, are being carried along one side of the row of stanchions, passing round the end, and returned along the other side. The guide wheels for the travelling chain can be seen at the end of the run. The electric hoists are shown overhead, both in this photograph and in Fig. 189.

The floor below is devoted to the treatment of offals, while the hides are dressed and stored on the ground floor. A separate equipment exists for the killing and freezing of

Fig. 189

The chilling building is of four floors, served by lifts. The chill rooms, which are cooled by brine spray, occupy the two centre floors. The ground floor is piped for direct expansion, and is used as a freezer chamber and for storage. The refrigerating plant, which is illustrated in Fig. 191, consists of two twin compressor 200 ton horizontal belt-driven ammonia machines, supplied by Messrs. L. Sterne & Co., Glasgow. Each machine is belt driven from direct current electric motors, the whole of the power being generated in the works power

Fig. 190

station. The buildings are all steel frame, with brick walls and reinforced concrete floors carried on steel beams. The insulation is of slab cork.

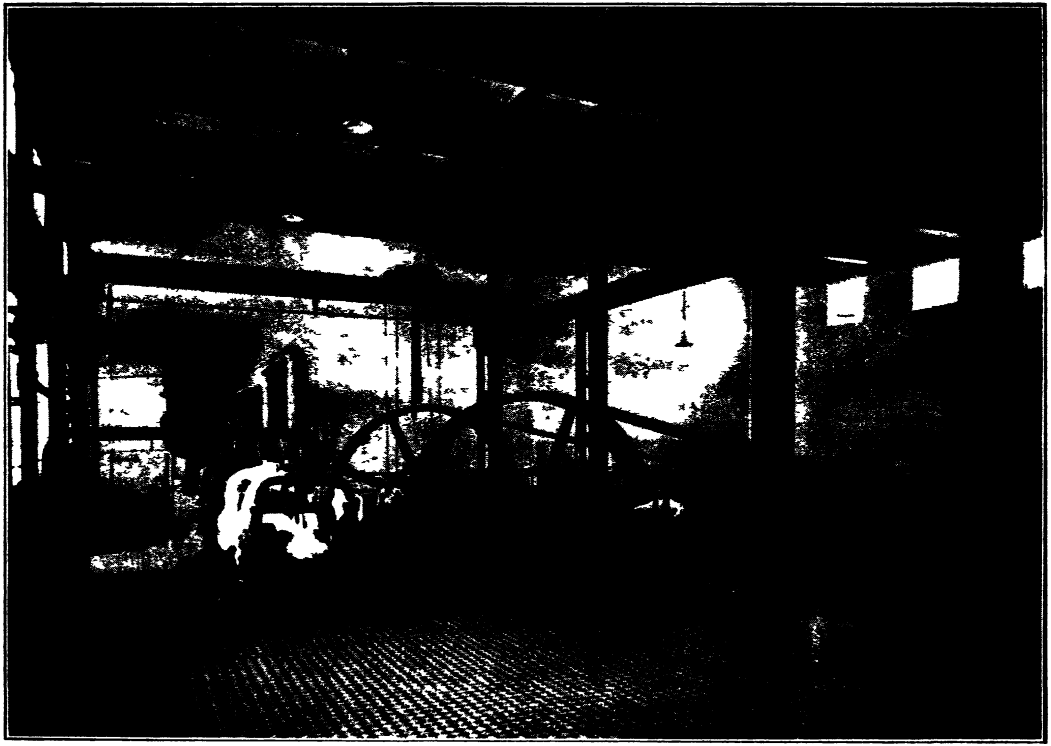


Fig. 191

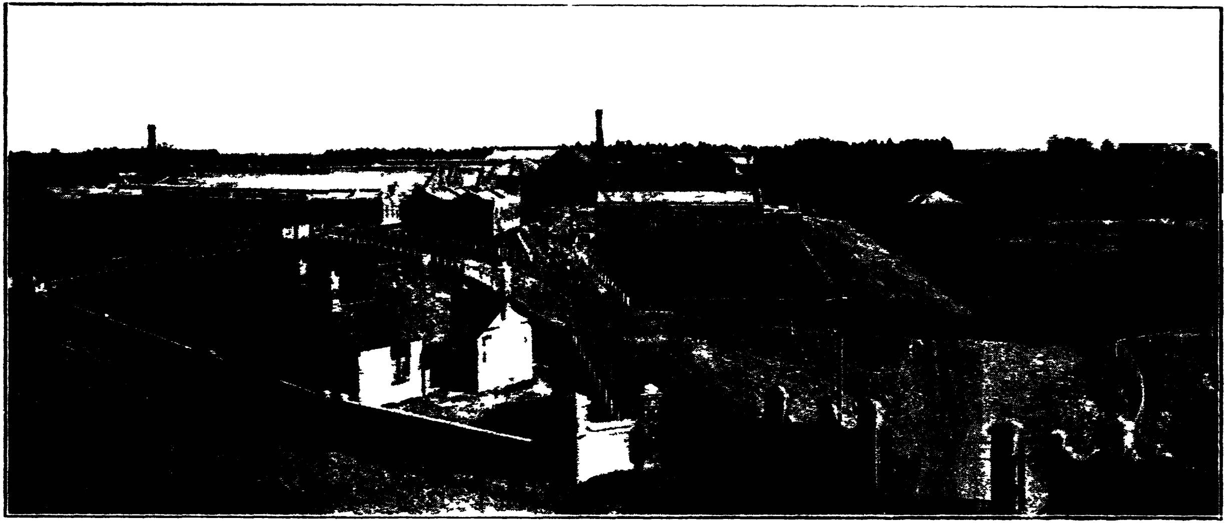


Fig. 192

Fig. 192 is a panoramic view of the Islington Works of the New Zealand Refrigerating Co., Ltd., near Christchurch. They have a daily killing and freezing capacity of 7,000 sheep and 50 cattle, while storage is provided for 375,000 carcasses.

The slaughter house for sheep at the Imlay Works of the same company is illustrated in Fig. 193. The sheep pens are at the back on either side, and are screened from the slaughter house by rising and falling shutters, shown also in Fig. 174, p. 495. The bleeding trough is shown as well as the openings in the floor for offal, skins, etc. From the slaughter house the carcasses pass to the cooling room, where they hang until they get rid of their animal heat. They are then passed, without any preliminary chilling, into the freezing room, which is held at a temperature of 10° F., and are frozen in twenty-four hours. While cooling, the carcasses are hung as shown in Fig. 194, which illustrates the cooling room at one of the New Zealand freezing works.

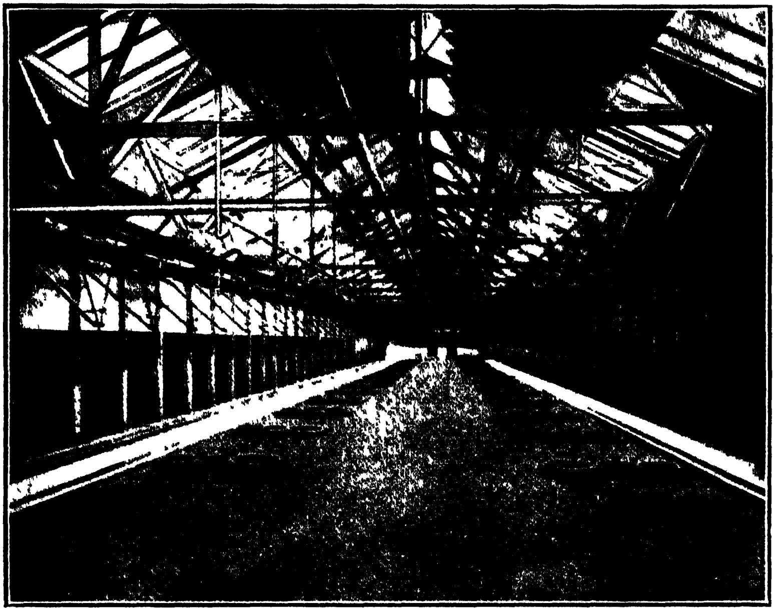


FIG. 193

It is necessary to have sufficient insulated storage spaces to take care of the meat accumulating between shipments, and for chilled meat this must, like the chilling rooms, be provided with a system of overhead running rails. Frozen beef, mutton, and lamb is not hung, but is stacked. A storage room for mutton is illustrated in Fig. 195 It is one of two chambers at the Imlay Works of the New Zealand Refrigerating Co., Ltd Each chamber has a floor space of over an acre, and the combined holding capacity of the two is 250,000 carcases of mutton.

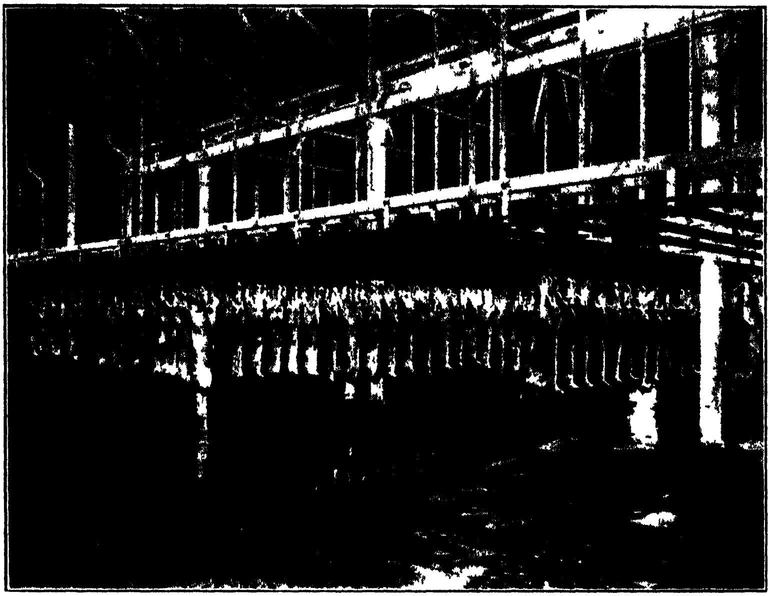


FIG 194

As has already been remarked, the profitable working of any meat works depends to a large extent upon the economic utilization and realization of the by-products. All fats are collected and graded for rendering. Inedible portions and offal go to the tank or digester house where, after the extraction of tallow the remainder is converted into fertilizer. Hides, hoofs, and bones have to be dealt with The blood is dried for fertilizer and every portion is utilized. The works are run on a strictly departmental basis, so that the costs and workings of each section can be separately analysed. The pelt department of the Islington Works, illustrated in Fig. 192, is shown in Fig. 196.

In building construction, a 16 ft. column spacing has been very generally adopted. This lends itself to a convenient distribution of the track work system, and it is suitable either for timber, for brick and steel or ferro-concrete construction. The earlier colonial slaughter houses were largely timber structures, weather boarded outside, the insulation of the freezing and chill rooms being formed by packing the wall spaces with the filling used. The present practice is to use more permanent materials, which have the advantage of being more impervious to moisture and consequently more sanitary. This advantage is particularly great in the case of floors. For the slaughter house proper a granolithic finish floor or a similar

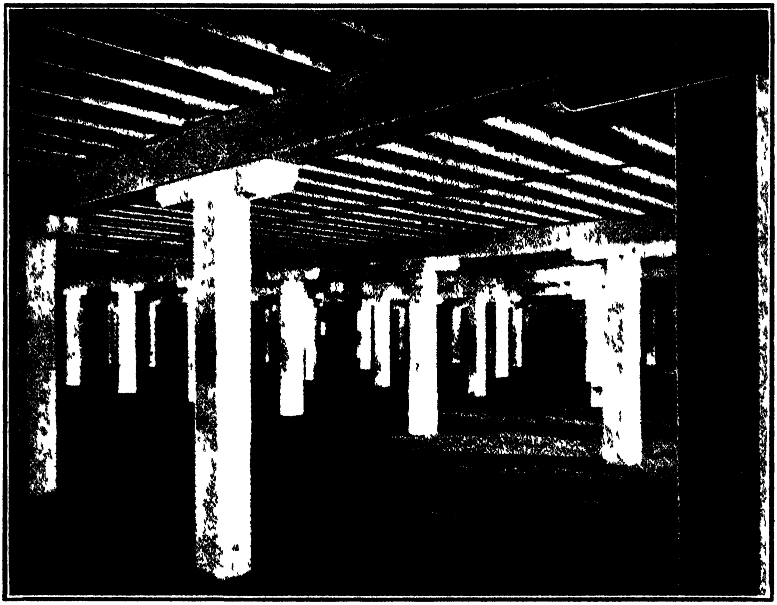


FIG. 195

hard and impervious surface is undoubtedly best. It must be arranged for suitable drainage, and all drains should empty into special fat collecting traps, from which the fat should be regularly collected and taken to the tank house.

The actual materials to be used for building must, of course, be determined by relative building costs at site, and the same holds true with regard to the insulation. The bulk of insulation is very large. The cost and particularly the freight on it is very high in the case of a large installation It is, therefore, preferable and more economical to use, if possible, some material that can be obtained locally, though its resistance to passage of heat may not be so great as the material in more regular use. Thus, in most of the meat works in Australia and New Zealand, charcoal or calcined pumice was very largely used. In modern works sheet cork has been exclusively employed in spite of its extra cost.

FIG. 196

Steam is necessary, in large quantities, for cooking in the tank house and for hot water supplies. It is also generally used as motive power. If the refrigerating machinery is steam driven, a separate plant is generally employed to generate electricity for the auxiliary machinery required throughout the building and for lighting. Where supplies of electric power can be obtained from the public supply, electricity can be used throughout, and the boilers are then only large enough to supply the necessary steam for heating and cooking. This makes a considerable reduction in the total first cost. Alternatively, in sites where coal is very expensive, crude oil engines are used to develop the required power.

In a freezing works the duties of the refrigerating plant are fairly well defined, and the refrigerating power can be calculated with a closer degree of accuracy than in the average plant for cold storage only. The unknown factors for which empirical allowances must be made represent a smaller proportion of the total work. It is necessary, however, here, as in every other case, to have a practical knowledge of the conditions to be met, and it is an advantage to be able to utilize results obtained from existing installations working under more or less similar conditions.

When the drawings have been prepared, and the insulation decided upon, the exposed surface can readily be obtained and an estimate made of the loss of heat through the insulation. The specific heat of meat above freezing point may vary between 0·75 and 0·8. Below freezing point it is about 0·4. The latent heat is about 100 B.T.U. or slightly over, so that taking the total weight of meat, including the edible offals that pass into store, an allowance of 160 B.T.U. per lb. of meat should be made. There is very little loss through the openings of the doors in the freezing rooms, but there is a considerable amount of work done in the preliminary beef chilling rooms, and allowances have to be made for this, together with the heating effect due to the lighting.

Refrigerating machinery is used to cool the water used for washing and chilling the fats, preparatory to their being cut up for rendering. Where the dispatch of chilled or frozen meat is effected by rail it is necessary to have an ice-making equipment for icing the refrigerator vans, together with some ice storage. The capacity of the ice-making plant depends entirely upon the quantity of the shipments made by rail.

It is always advisable to arrange the plant so that extensions can be readily made and connected up. The machinery itself should be in at least two units so that there is a complete standby, or a very good arrangement is to have three compressors, two of which will carry the working load. A standby should also be provided for the electric generator, as current is required continuously, and the effects of a breakdown at a busy period would be disastrous. Apart from the power required for making ice, a rough and ready rule for average conditions is to allow about 20,000 cu. in. compressor volume per minute (i.e. roughly about 2½ tons refrigeration) per ton of meat to be frozen per day.

Fat Rendering. The method commonly in use in meat works for dealing with fats has been what is known as the "wet" process, which is, of course, well known, hence the term "Tank Room." To-day, the "wet" process is almost obsolete, its place being taken by the "dry" process, in which the material to be rendered does not come in direct contact with steam, but is melted in a vessel by steam heat. The melter is provided with revolving arms which keep the material constantly on the move. As the fat melts out it is removed through a fat pipe, and when the process is completed the residue, termed cracklings, is discharged and either pressed in an expeller, or put into a centrifugal machine of special construction to rid it of any remaining fat. As refrigeration does not enter into either process they need not be further referred to here.

Bacon Factories

For curing in bacon factories a steady temperature of 38 to 40° F. is required. The first essential for a bacon factory is, of course, a regular supply of the right type of bacon pig, but this is rather outside the province of the refrigerating engineer. A bacon factory must commence with an ample covered lairage space. The gates to the pens should be made double hinged, so that they can not only be swung inwards or outwards, but also either from right or left-hand to permit convenient handling and sorting of the pigs entering and leaving. In modern factories the pigs ascend a slope to the first floor, on which killing is carried out as in the modern abattoir. Smaller factories, dealing with, say, 1,000 pigs per day, are often on the score of expense arranged entirely on one floor. From the lairage pens the pigs are driven as required to the catching pen. Here a shackle is attached to *one* hind leg—not both—and hooked to a short chain secured to a big wheel, the driving side of which is shown in Fig. 197, or to a chain elevator which is kept constantly at work.

After passing the highest point of the wheel or elevator the pig is automatically transferred to the track rail, and passed along to the sticking pen where the sticker stands, and then to the bleeding passage. The rail is arranged with an offset or turn between the catching pen and bleeding passage, so that the pigs outside are kept in happy ignorance of the fate awaiting them.

It is essential for successful bacon curing that there should be a complete drainage of blood from the carcass, and for this reason the mechanical killer, which first of all stuns the animal and thus stems the circulation of blood, are unsuitable. The method of killing employed has met with criticism from the various humanitarian societies, and in this connection a demonstration of the different methods of slaughtering animals for food was held by them at the Birmingham abattoirs. It was attended by a large and representative gathering of medical officers of health, members of health and sanitary committees, veterinary surgeons and market inspectors, representatives of the R.S.P.C.A., and other societies whose object is the promotion of slaughter by mechanical methods, as well as by representatives of the Federation of Meat Traders' Association. Pigs were killed in the manner described above and also by mechanical killers operated by " an intelligent official, highly trained in the use of a pistol." Dr. Leonard Hill, M.B., F.R.S., who was present and who is, of course, a recognized authority on these matters, published an exceedingly interesting article in *The Lancet** on the demonstration.

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* *The Lancet*, 22nd December, 1923, p. 1382.

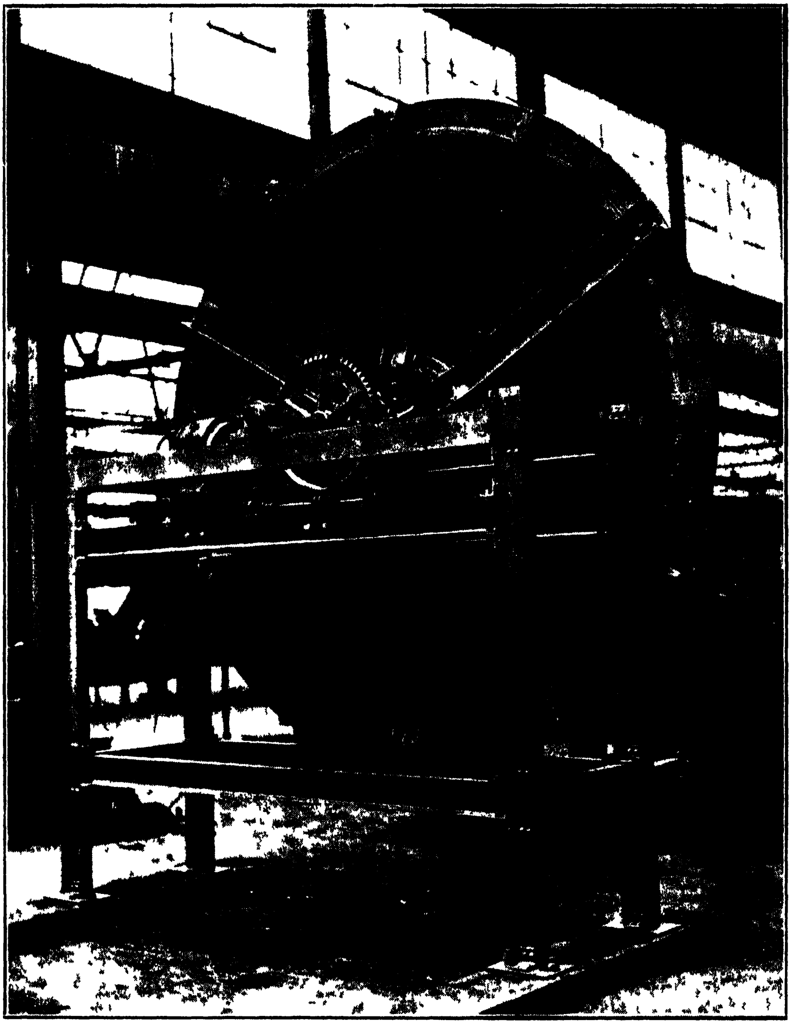

FIG. 197

This article should be read by everybody interested His conclusion was as follows—

> The butchers and bacon curers are then right in their contention, and on the grounds of humanity, economy, and proper carrying out of

a great business they should not be prevented from continuing the old methods of slaughter. These methods have been found right, through ages of human experience. It is clear that bleeding is most rapid and complete in the head down position, and I would urge that all pigs are killed in this position.

The time from the moment of shackling until the pig is stuck and dead is a few seconds only, a rapid end which the ordinary human being might perhaps envy. The animals exhibit a remarkable quiescence. Now, the pig is what is known as a full-blooded animal. It cannot stand going downhill, and if it is placed in an inverted position the blood rushes to its head and renders it insensible. If a young pig is picked up and held in the arms like a child it will squeal the house down—if it is caught by the hind legs and held by them, with its head downwards, it will be silent. The bacon manufacturers have merely made use of this characteristic to enable them to kill their pigs quickly without pain and with perfect bleeding. Even so, it is recognized that a method of rendering the animal unconscious before sticking, and without causing blood splashing, would have many advantages.

Fortunately, this is to hand in the apparatus invented by Professor M. Muller* which has been developed with perfect success and is now in regular use for producing anaesthesia in pigs, calves, and sheep, in the more up-to-date slaughterhouses in England. The apparatus is illustrated in Fig. 198. The tong-like electrodes shown in the illustration are applied to the head—behind the ears of the pig, and between the ear and the eye of sheep and calves. The application of a pressure of 60 to 70 volts of alternating current, or specially interrupted direct current, for from 10 to 40 seconds according to the size of the animal, produces immediate unconsciousness and permits castration or slaughter to be carried out with perfect freedom from preliminary distress.

An interesting report on the use of the apparatus, by Professors Symes, Hill, and Hobday, appeared in the Veterinary Record of 23rd April, 1932. The report was entirely favourable to the apparatus. The conclusions reached by Professor Hill, who has been previously quoted, being that "The method is the most perfect and humane method of slaughtering we have yet seen." The operation is very rapid, up to 300 pigs per hour having been stunned by one man with one pair of tongs.

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* The General Radiological and Surgical Apparatus Co., Ltd., 204–206 Great Portland Street, London, W.1.

The blood is collected and pumped to the digesters. When the carcass is fully drained it is pushed along the rail and lowered into a scalding tank, fitted with steam heating coils, which maintain the water at the required temperature. Here the carcass is immersed and turned over and over until the hairs are loosened. The tank is provided with a cradle, by means of which the carcass is lifted out and dumped on to a scuttling table, where the hair is removed. In larger factories

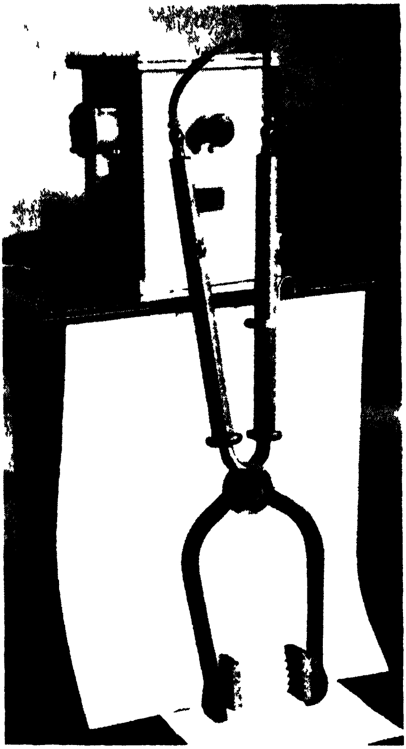

FIG. 198

machines are used for this purpose, but even with them a certain amount of handwork is generally necessary. When the hair is removed the carcasses are passed into the singeing furnace. There are various constructions of coal and gas fired furnaces, but oil is almost invariably used. The carcass is exposed to the flame for a short time. It is then passed along the running rail under sprinklers which cool it down. The dirt and sediment resulting from the process of singeing is removed before it passes on to the dressing rail. So far, refrigeration has not been required, nor is it called into use until the carcasses eventually find their way to the "cellar." This term is, of course, a relic of pre-refrigeration days, when the use of cellars was a necessity for bacon curing, as a deep cellar often cooled by natural ice provided the only means of obtaining a moderate and at the same time even temperature.

The chill room and curing cellar can be insulated in any approved manner, but with the curing cellar particularly, care must be taken that the floor is of an impervious nature. Before the advent of cork slabs and an asphalt or granolithic finish for the internal floors of cold stores, it was often considered best not to attempt any regular insulation for the floors of curing cellars. The temperature required is relatively a high one, and the moisture and salt in a curing cellar generally hopelessly damaged the insulation of timber and loose fillings.

The rail system on which the carcasses are hung and conveyed is extended into the chill room, as the sides must be hung until chilled and ready for curing. Outside the insulated rooms it is important to see that the lay-out of the rails is arranged in such a way that the various portions are taken in their correct sequence with a minimum of labour and movement. Both the chill and curing rooms are, as a rule, cooled by means of a large diameter brine piping suspended from the ceilings, with drip gutters arranged underneath them. It is an advantage to provide, in addition, an air cooler for the chill room to assist in rapid cooling, and where it can conveniently be arranged, the air ducts should be extended to the curing room so that the air in these may be changed if required. The air circulation should not, in any case, be a vigorous one, and a complete absence of forced circulation in the curing rooms is preferable on account of the loss of weight which it occasions, a humid atmosphere here being a great advantage. With a factory killing 3,000 pigs a day, it will be readily realized that the value of pigs flesh in the cellar runs into many thousands of pounds. A breakdown in the refrigerating plant would jeopardize the whole of this, and consequently the greatest care should be taken not only in the design of the refrigerating plant to guard against breakdown, but it must be in duplicate. With the Ayrshire and Danish cures the bacon is only kept in the cellars for seven days, and in this case duplication is not so important as the value undergoing cure is not so great.

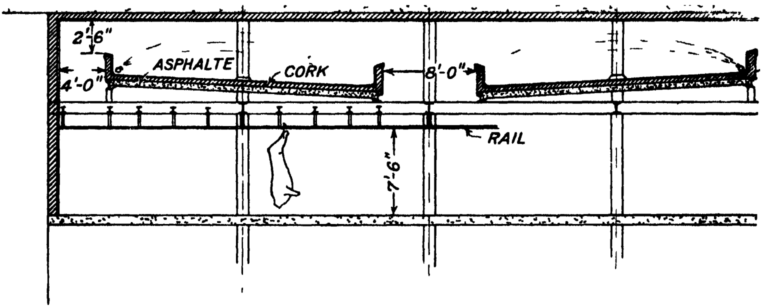

FIG. 199

In the United States it is the custom to dispense entirely with the hanging room, and to run the hot hogs straight from killing and dressing into the chill rooms. This practice puts a greater duty on the refrigeration in these rooms than that to which users in this country are accustomed, and consequently chill rooms are nearly always fitted with curtain or spray lofts. Chilling is very rapid, but the practice is not regarded with favour by English bacon curers. A spray loft, as applied to hog coolers, is illustrated in Fig. 199. It will be seen that the lofts are formed with upcast shafts for the hot air and downcast shafts for the cold air. The spray pipes are fixed about 3 or 4 ft. from the ceiling of the chamber, to allow for access and supervision. The false floor below them must be

FIG. 200

FIG. 201

well insulated to prevent the warm air in the room condensing upon the underside, and dripping on to the hogs hanging below. The chill rooms are designed on a basis of 3 sq. ft. of floor space per hog, which is a little less than the usual

FIG 202

allowance in England. The brine is cooled to a temperature of about 16° F., and is circulated through the spray nozzles at the rate of about 0·25 of a gallon of brine per hog per minute. At this temperature and rate of circulation the time required to chill the hogs to a temperature of 32° F. is thirty hours. Actually it is not possible in the usual plant to maintain brine at this temperature, because the hogs are put into the chill room with all their animal heat in them, and consequently the temperature of the brine rises. To overcome this difficulty there is always an alternative supply of low temperature brine, which is turned on while the first supply is being re-chilled.

The refrigerating plant is generally used to cool a separate room in which the edible portions, which are sold separately, are stored. It is sometimes used, in addition, to cool the pickle, but the ordinary practice is to place the tanks containing the pickle in the curing room or cellar itself. The

FIG. 203

fat removed from the carcasses is rendered for lard. The usual practice in this country is to run the liquid lard, after it has been refined and settled, through measuring valves direct into the cartons and let it cool there. In the United States, where compound lard is largely manufactured, it is cooled on a special chiller of the rotary drum type, through which cold brine is circulated, a scraper knife removing the lard as it is consolidated on the surface of the drum.

FIG 204

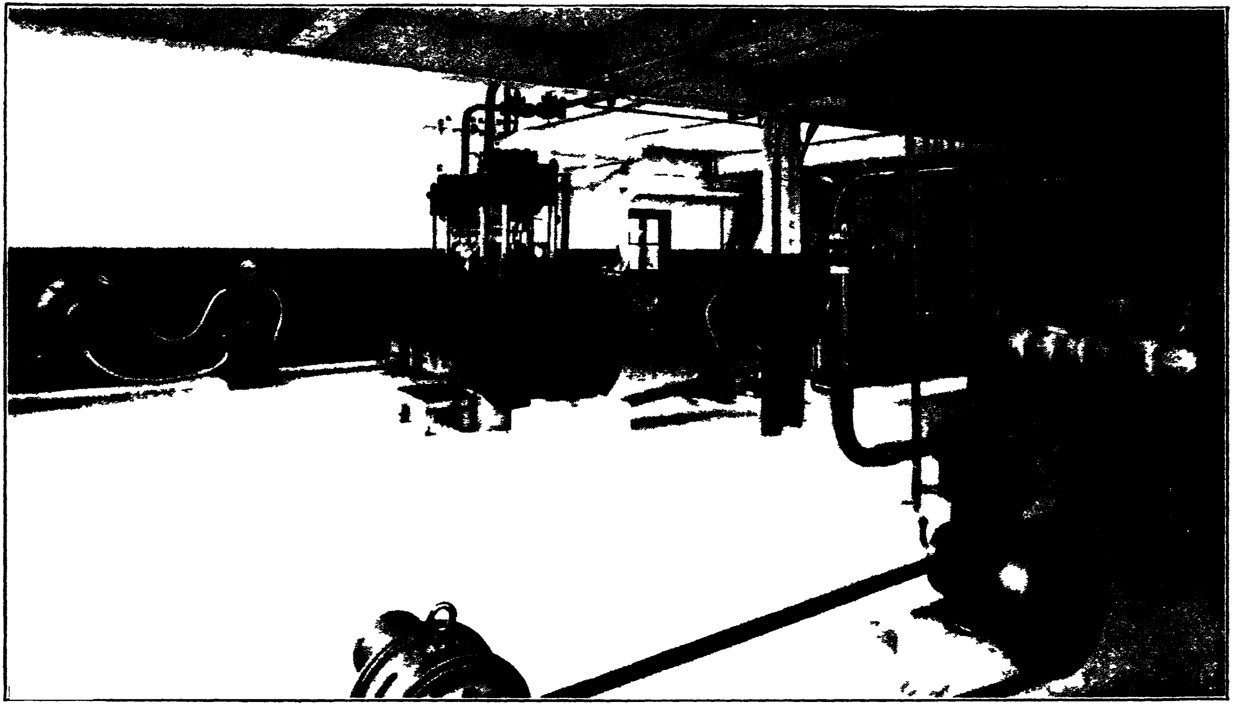

FIG 205

The accompanying illustrations have been taken in a modern bacon factory designed by the author to deal with 3,000 pigs a week. There is nothing wasted in a modern bacon factory, all parts being used. The casings are cleaned ; all offal goes to a digester plant, which should preferably be of the dry type, for conversion into fertilizer, and a similar machine is often used for blood drying. The equipment of the factory must, of course, include the necessary smoke houses, and very frequently a sausage making department is incorporated. The slaughter floor is illustrated in Fig. 200. The scalding tank is in the far corner, and the end of the rail, down which the carcasses travel after bleeding, can just be distinguished. Below this is the scalding tank. and at the near end of the tank is the de-hairing machine. The concrete tanks on the right are part of the "inwards department," where the intestines are dealt with. The hanging room is illustrated in Fig. 201, which shows the overhead track and the carcasses hanging up to cool off their animal heat. The entrance to the chill rooms on the floor below is shown in Fig. 202, one

FIG. 206

of the six chill rooms in Fig. 203, the curing cellars in Fig. 204, and the engine room with duplicate electrically driven ammonia compressors in Fig. 205. The small air compressor in the foreground is used for elevating the sewage, as the land on which the factory was built was below the level of the public sewer. The digester or manure department is shown in Fig. 206.

TABLE 1.—Saturated Ammonia: Temperature Table.

Temp. °F.	Pressure.		Volume vapor. ft^3/lb.	Density vapor. lbs./ft.^{3}	Heat content.		Latent heat. Btu./lb.	Entropy		Temp. °F.
	Absolute. lbs./in.^{2}	Gage. lbs./in.^{2}			Liquid. Btu./lb.	Vapor. Btu /lb.		Liquid. Btu./lb.°F.	Vapor. Btu./lb.°F.	
t	p	$g.p.$	V	$1/V$	h	H	L	s	S	t
−60	5.55	*18.6	44.73	0.02235	−21.2	589.6	610.8	−0.0517	1.4769	−60
−59	5.74	*18.2	43.37	.02306	−20.1	590.0	610.1	−.0490	.4741	−59
−58	5.93	*17.8	42.05	.02378	−19.1	590.4	609.5	−.0464	.4713	−58
−57	6.13	*17.4	40.79	.02452	−18.0	590.8	608.8	−.0438	.4686	−57
−56	6.33	*17.0	39.56	.02528	−17.0	591.2	608.2	−.0412	.4658	−56
−55	6.54	*16.6	38.38	0.02605	−15.9	591.6	607.5	−0.0386	1.4631	−55
−54	6.75	*16.2	37.24	.02685	−14.8	592.1	606.9	.0360	.4604	−54
−53	6.97	*15.7	36.15	.02766	−13.8	592.4	606.2	−.0334	.4577	−53
−52	7.20	*15.3	35.09	.02850	−12.7	592.9	605.6	−.0307	.4551	−52
−51	7.43	*14.8	34.06	.02936	−11.7	593.2	604.9	−.0281	.4524	−51
−50	7.67	*14.3	33.08	0.03023	−10.6	593.7	604.3	−0.0256	1.4497	−50
−49	7.91	*13.8	32.12	.03113	−9.6	594.0	603.6	−.0230	.4471	−49
−48	8.16	*13.3	31.20	.03205	−8.5	594.4	602.9	−.0204	.4445	−48
−47	8.42	*12.8	30.31	.03299	−7.4	594.9	602.3	−.0179	.4419	−47
−46	8.68	*12.2	29.45	.03395	−6.4	595.2	601.6	−.0153	.4393	−46
−45	8.95	*11.7	28.62	0.03494	−5.3	595.6	600.9	−0.0127	1.4368	−45
−44	9.23	*11.1	27.82	.03595	−4.3	596.0	600.3	−.0102	.4342	−44
−43	9.51	*10.6	27.04	.03698	−3.2	596.4	599.6	−.0076	.4317	−43
−42	9.81	*10.0	26.29	.03804	−2.1	596.8	598.9	−.0051	.4292	−42
−41	10.10	*9.3	25.56	.03912	−1.1	597.2	598.3	−.0025	.4267	−41
−40	10.41	*8.7	24.86	0.04022	0.0	597.6	597.6	0.0000	1.4242	−40
−39	10.72	*8.1	24.18	.04135	1.1	598.0	596.9	.0025	.4217	−39
−38	11.04	*7.4	23.53	.04251	2.1	598.3	596.2	.0051	.4193	−38
−37	11.37	*6.8	22.89	.04369	3.2	598.7	595.5	.0076	.4169	−37
−36	11.71	*6.1	22.27	.04489	4.3	599.1	594.8	.0101	.4144	−36
−35	12.05	*5.4	21.68	0.04613	5.3	599.5	594.2	0.0126	1.4120	−35
−34	12.41	*4.7	21.10	.04739	6.4	599.9	593.5	.0151	.4096	−34
−33	12.77	*3.9	20.54	.04868	7.4	600.2	592.8	.0176	.4072	−33
−32	13.14	*3.2	20.00	.04999	8.5	600.6	592.1	.0201	.4048	−32
−31	13.52	*2.4	19.48	.05134	9.6	601.0	591.4	.0226	.4025	−31
−30	13.90	*1.6	18.97	0.05271	10.7	601.4	590.7	0.0250	1.4001	−30
−29	14.30	*0.8	18.48	.05411	11.7	601.7	590.0	.0275	.3978	−29
−28	14.71	0.0	18.00	.05555	12.8	602.1	589.3	.0300	.3955	−28
−27	15.12	0.4	17.54	.05701	13.9	602.5	588.6	.0325	.3932	−27
−26	15.55	0.8	17.09	.05850	14.9	602.8	587.9	.0350	.3909	−26
−25	15.98	1.3	16.66	0.06003	16.0	603.2	587.2	0.0374	1.3886	−25
−24	16.42	1.7	16.24	.06158	17.1	603.6	586.5	.0399	.3863	−24
−23	16.88	2.2	15.83	.06317	18.1	603.9	585.8	.0423	.3840	−23
−22	17.34	2.6	15.43	.06479	19.2	604.3	585.1	.0448	.3818	−22
−21	17.81	3.1	15.05	.06644	20.3	604.6	584.3	.0472	.3796	−21
−20	18.30	3.6	14.68	0.06813	21.4	605.0	583.6	0.0497	1.3774	−20
−19	18.79	4.1	14.32	.06985	22.4	605.3	582.9	.0521	.3752	−19
−18	19.30	4.6	13.97	.07161	23.5	605.7	582.2	.0545	.3729	−18
−17	19.81	5.1	13.62	.07340	24.6	606.1	581.5	.0570	.3708	−17
−16	20.34	5.6	13.29	.07522	25.6	606.4	580.8	.0594	.3686	−16
−15	20.88	6.2	12.97	0.07709	26.7	606.7	580.0	0.0618	1.3664	−15
−14	21.43	6.7	12.66	.07898	27.8	607.1	579.3	.0642	.3643	−14
−13	21.99	7.3	12.36	.08092	28.9	607.5	578.6	.0666	.3621	−13
−12	22.56	7.9	12.06	.08289	30.0	607.8	577.8	.0690	.3600	−12
−11	23.15	8.5	11.78	.08490	31.0	608.1	577.1	.0714	.3579	−11
−10	23.74	9.0	11.50	0.08695	32.1	608.5	576.4	0.0738	1.3558	−10

* Inches of mercury below one standard atmosphere (29.92 in.).

TABLE 1.—Saturated Ammonia Temperature Table—Continued

Temp °F	Pressure		Volume vapor ft³/lb	Density vapor lbs/ft³	Heat content		Latent heat Btu/lb	Entropy		Temp °F
	Absolute lbs/in²	Gage lbs/in²			Liquid Btu/lb	Vapor Btu/lb		Liquid Btu/lb °F	Vapor Btu/lb °F	
t	p	$g\ p$	V	$1/V$	h	H	L	s	S	t
−10	23.74	9.0	11.50	0.08695	32.1	608.5	576.4	0.0738	1.3558	**−10**
−9	24.35	9.7	11.23	.08904	33.2	608.8	575.6	.0762	.3537	−9
−8	24.97	10.3	10.97	.09117	34.3	609.2	574.9	.0786	.3516	−8
−7	25.61	10.9	10.71	.09334	35.4	609.5	574.1	.0809	.3495	−7
−6	26.26	11.6	10.47	.09555	36.4	609.8	573.4	.0833	.3474	−6
−5	26.92	12.2	10.23	0.09780	37.5	610.1	572.6	0.0857	1.3454	**−5**
−4	27.59	12.9	9.991	.1001	38.6	610.5	571.9	.0880	.3433	−4
−3	28.28	13.6	9.763	.1024	39.7	610.8	571.1	.0904	.3413	−3
−2	28.98	14.3	9.541	.1048	40.7	611.1	570.4	.0928	.3393	−2
−1	29.69	15.0	9.326	.1072	41.8	611.4	569.6	.0951	.3372	−1
0	30.42	15.7	9.116	0.1097	42.9	611.8	568.9	0.0975	1.3352	**0**
1	31.16	16.5	8.912	.1122	44.0	612.1	568.1	.0998	.3332	1
2	31.92	17.2	8.714	.1148	45.1	612.4	567.3	.1022	.3312	2
3	32.69	18.0	8.521	.1174	46.2	612.7	566.5	.1045	.3292	3
4	33.47	18.8	8.333	.1200	47.2	613.0	565.8	.1069	.3273	4
5	34.27	19.6	8.150	0.1227	48.3	613.3	565.0	0.1092	1.3253	**5**
6	35.09	20.4	7.971	.1254	49.4	613.6	564.2	.1115	.3234	6
7	35.92	21.2	7.798	.1282	50.5	613.9	563.4	.1138	.3214	7
8	36.77	22.1	7.629	.1311	51.6	614.3	562.7	.1162	.3195	8
9	37.63	22.9	7.464	.1340	52.7	614.6	561.9	.1185	.3176	9
10	38.51	23.8	7.304	0.1369	53.8	614.9	561.1	0.1208	1.3157	**10**
11	39.40	24.7	7.148	.1399	54.9	615.2	560.3	.1231	.3137	11
12	40.31	25.6	6.996	.1429	56.0	615.5	559.5	.1254	.3118	12
13	41.24	26.5	6.847	.1460	57.1	615.8	558.7	.1277	.3099	13
14	42.18	27.5	6.703	.1492	58.2	616.1	557.9	.1300	.3081	14
15	43.14	28.4	6.562	0.1524	59.2	616.3	557.1	0.1323	1.3062	**15**
16	44.12	29.4	6.425	.1556	60.3	616.6	556.3	.1346	.3043	16
17	45.12	30.4	6.291	.1590	61.4	616.9	555.5	.1369	.3025	17
18	46.13	31.4	6.161	.1623	62.5	617.2	554.7	.1392	.3006	18
19	47.16	32.5	6.034	.1657	63.6	617.5	553.9	.1415	.2988	19
20	48.21	33.5	5.910	0.1692	64.7	617.8	553.1	0.1437	1.2969	**20**
21	49.28	34.6	5.789	.1728	65.8	618.0	552.2	.1460	.2951	21
22	50.36	35.7	5.671	.1763	66.9	618.3	551.4	.1483	.2933	22
23	51.47	36.8	5.556	.1800	68.0	618.6	550.6	.1505	.2915	23
24	52.59	37.9	5.443	.1837	69.1	618.9	549.8	.1528	.2897	24
25	53.73	39.0	5.334	0.1875	70.2	619.1	548.9	0.1551	1.2879	**25**
26	54.90	40.2	5.227	.1913	71.3	619.4	548.1	.1573	.2861	26
27	56.08	41.4	5.123	.1952	72.4	619.7	547.3	.1596	.2843	27
28	57.28	42.6	5.021	.1992	73.5	619.9	546.4	.1618	.2825	28
29	58.50	43.8	4.922	.2032	74.6	620.2	545.6	.1641	.2808	29
30	59.74	45.0	4.825	0.2073	75.7	620.5	544.8	0.1663	1.2790	**30**
31	61.00	46.3	4.730	.2114	76.8	620.7	543.9	.1686	.2773	31
32	62.29	47.6	4.637	.2156	77.9	621.0	543.1	.1708	.2755	32
33	63.59	48.9	4.547	.2199	79.0	621.2	542.2	.1730	.2738	33
34	64.91	50.2	4.459	.2243	80.1	621.5	541.4	.1753	.2721	34
35	66.26	51.6	4.373	0.2287	81.2	621.7	540.5	0.1775	1.2704	**35**
36	67.63	52.9	4.289	.2332	82.3	622.0	539.7	.1797	.2686	36
37	69.02	54.3	4.207	.2377	83.4	622.2	538.8	.1819	.2669	37
38	70.43	55.7	4.126	.2423	84.6	622.5	537.9	.1841	.2652	38
39	71.87	57.2	4.048	.2470	85.7	622.7	537.0	.1863	.2635	39
40	73.32	58.6	3.971	0.2518	86.8	623.0	536.2	0.1885	1.2618	**40**

TABLE 1 —Saturated Ammonia Temperature Table—Continued

Temp °F	Pressure		Volume vapor ft³/lb	Density vapor lbs/ft³	Heat content		Latent heat Btu/lb	Entropy		Temp °F
	Absolute lbs/in²	Gage lbs/in²			Liquid Btu/lb	Vapor Btu/lb		Liquid Btu/lb °F	Vapor Btu/lb °F	
t	p	g p	V	$1/V$	h	H	L	s	S	t
40	73 32	58 6	3 971	0 2518	86 8	623 0	536 2	0 1885	1 2618	**40**
41	74 80	60 1	3 897	2566	87 9	623 2	535 3	1908	2602	41
42	76 31	61 6	3 823	2616	89 0	623 4	534 4	1930	2585	42
43	77 83	63 1	3 752	2665	90 1	623 7	533 6	1952	2568	43
44	79 38	64 7	3 682	2716	91 2	623 9	532 7	1974	2552	44
45	80 96	66 3	3 614	0 2767	92 3	624 1	531 8	0 1996	1 2535	**45**
46	82 55	67 9	3 547	2819	93 5	624 4	530 9	2018	2519	46
47	84 18	69 5	3 481	2872	94 6	624 6	530 0	2040	2502	47
48	85 82	71 1	3 418	2926	95 7	624 8	529 1	2062	2486	48
49	87 49	72 8	3 355	2981	96 8	625 0	528 2	2083	2469	49
50	89 19	74 5	3 294	0 3036	97 9	625 2	527 3	0 2105	1 2453	**50**
51	90 91	76 2	3 234	3092	99 1	625 5	526 4	2127	2437	51
52	92 66	78 0	3 176	3149	100 2	625 7	525 5	2149	2421	52
53	94 43	79 7	3 119	3207	101 3	625 9	524 6	2171	2405	53
54	96 23	81 5	3 063	3265	102 4	626 1	523 7	2192	2389	54
55	98 06	83 4	3 008	0 3325	103 5	626 3	522 8	0 2214	1 2373	**55**
56	99 91	85 2	2 954	3385	104 7	626 5	521 8	2236	2357	56
57	101 8	87 1	2 902	3446	105 8	626 7	520 9	2257	2341	57
58	103 7	89 0	2 851	3508	106 9	626 9	520 0	2279	2325	58
59	105 6	90 9	2 800	3571	108 1	627 1	519 0	2301	2310	59
60	107 6	92 9	2 751	0 3635	109 2	627 3	518 1	0 2322	1 2294	**60**
61	109 6	94 9	2 703	3700	110 3	627 5	517 2	2344	2278	61
62	111 6	96 9	2 656	3765	111 5	627 7	516 2	2365	2262	62
63	113 6	98 9	2 610	3832	112 6	627 9	515 3	2387	2247	63
64	115 7	101 0	2 565	3899	113 7	628 0	514 3	2408	2231	64
65	117 8	103 1	2 520	0 3968	114 8	628 2	513 4	0 2430	1 2216	**65**
66	120 0	105 3	2 477	4037	116 0	628 4	512 4	2451	2201	66
67	122 1	107 4	2 435	4108	117 1	628 6	511 5	2473	2186	67
68	124 3	109 6	2 393	4179	118 3	628 8	510 5	2494	2170	68
69	126 5	111 8	2 352	4251	119 4	628 9	509 5	2515	2155	69
70	128 8	114 1	2 312	0 4325	120 5	629 1	508 6	0 2537	1 2140	**70**
71	131 1	116 4	2 273	4399	121 7	629 3	507 6	2558	2125	71
72	133 4	118 7	2 235	4474	122 8	629 4	506 6	2579	2110	72
73	135 7	121 0	2 197	4551	124 0	629 6	505 6	2601	2095	73
74	138 1	123 4	2 161	4628	125 1	629 8	504 7	2622	2080	74
75	140 5	125 8	2 125	0 4707	126 2	629 9	503 7	0 2643	1 2065	**75**
76	143 0	128 3	2 089	4786	127 4	630 1	502 7	2664	2050	76
77	145 4	130 7	2 055	4867	128 5	630 2	501 7	2685	2035	77
78	147 9	133 2	2 021	4949	129 7	630 4	500 7	2706	2020	78
79	150 5	135 8	1 988	5031	130 8	630 5	499 7	2728	2006	79
80	153 0	138 3	1 955	0 5115	132 0	630 7	498 7	0 2749	1 1991	**80**
81	155 6	140 9	1 923	5200	133 1	630 8	497 7	2769	1976	81
82	158 3	143 6	1 892	5287	134 3	631 0	496 7	2791	1962	82
83	161 0	146 3	1 861	5374	135 4	631 1	495 7	2812	1947	83
84	163 7	149 0	1 831	5462	136 6	631 3	494 7	2833	1933	84
85	166 4	151 7	1 801	0 5552	137 8	631 4	493 6	0 2854	1 1918	**85**

TABLE 1 —Saturated Ammonia Temperature Table—Continued

Temp °F	Pressure		Volume vapor ft^3/lb	Density vapor lbs/ft^3	Heat content		Latent heat Btu/lb	Entropy		Temp °F
	Absolute lbs/in^2	Gage lbs/in^2			Liquid Btu/lb	Vapor Btu/lb		Liquid Btu/lb °F	Vapor Btu/lb °F	
t	p	gp	V	$1/V$	h	H	L	s	S	t
85	166.4	151.7	1.801	0.5552	137.8	631.4	493.6	0.2854	1.1918	**85**
86	169.2	154.5	1.772	5643	138.9	631.5	492.6	2875	1904	86
87	172.0	157.3	1.744	5735	140.1	631.7	491.6	2895	1889	87
88	174.8	160.1	1.716	5828	141.2	631.8	490.6	2917	1875	88
89	177.7	163.0	1.688	5923	142.4	631.9	489.5	2937	1860	89
90	180.6	165.9	1.661	0.6019	143.5	632.0	488.5	0.2958	1.1846	**90**
91	183.6	168.9	1.635	6116	144.7	632.1	487.4	2979	1832	91
92	186.6	171.9	1.609	6214	145.8	632.2	486.4	3000	1818	92
93	189.6	174.9	1.584	6314	147.0	632.3	485.3	3021	1804	93
94	192.7	178.0	1.559	6415	148.2	632.5	484.3	3041	1789	94
95	195.8	181.1	1.534	0.6517	149.4	632.6	483.2	0.3062	1.1775	**95**
96	198.9	184.2	1.510	6620	150.5	632.6	482.1	3083	1761	96
97	202.1	187.4	1.487	6725	151.7	632.8	481.1	3104	1747	97
98	205.3	190.6	1.464	6832	152.9	632.9	480.0	3125	1733	98
99	208.6	193.9	1.441	6939	154.0	632.9	478.9	3145	1719	99
100	211.9	197.2	1.419	0.7048	155.2	633.0	477.8	0.3166	1.1705	**100**
101	215.2	200.5	1.397	7159	156.4	633.1	476.7	3187	1691	101
102	218.6	203.9	1.375	7270	157.6	633.2	475.6	3207	1677	102
103	222.0	207.3	1.354	7384	158.7	633.3	474.6	3228	1663	103
104	225.4	210.7	1.334	7498	159.9	633.4	473.5	3248	1649	104
105	228.9	214.2	1.313	0.7615	161.1	633.4	472.3	0.3269	1.1635	**105**
106	232.5	217.8	1.293	7732	162.3	633.5	471.2	3289	1621	106
107	236.0	221.3	1.274	7852	163.5	633.6	470.1	3310	1607	107
108	239.7	225.0	1.254	7972	164.6	633.6	469.0	3330	1593	108
109	243.3	228.6	1.235	8095	165.8	633.7	467.9	3351	1580	109
110	247.0	232.3	1.217	0.8219	167.0	633.7	466.7	0.3372	1.1566	**110**
111	250.8	236.1	1.198	8344	168.2	633.8	465.6	3392	1552	111
112	254.5	239.8	1.180	8471	169.4	633.8	464.4	3413	1538	112
113	258.4	243.7	1.163	8600	170.6	633.9	463.3	3433	1524	113
114	262.2	247.5	1.145	8730	171.8	633.9	462.1	3453	1510	114
115	266.2	251.5	1.128	0.8862	173.0	633.9	460.9	0.3474	1.1497	**115**
116	270.1	255.4	1.112	8996	174.2	634.0	459.8	3495	1483	116
117	274.1	259.4	1.095	9132	175.4	634.0	458.6	3515	1469	117
118	278.2	263.5	1.079	9269	176.6	634.0	457.4	3535	1455	118
119	282.3	267.6	1.063	9408	177.8	634.0	456.2	3556	1441	119
120	286.4	271.7	1.047	0.9549	179.0	634.0	455.0	0.3576	1.1427	**120**
121	290.6	275.9	1.032	9692	180.2	634.0	453.8	3597	1414	121
122	294.8	280.1	1.017	9837	181.4	634.0	452.6	3618	1400	122
123	299.1	284.4	1.002	9983	182.6	634.0	451.4	3638	1386	123
124	303.4	288.7	0.987	1.0132	183.9	634.0	450.1	3659	1372	124
125	307.8	293.1	0.973	1.028	185.1	634.0	448.9	0.3679	1.1358	**125**

TABLE II

PROPERTIES OF ETHYL CHLORIDE

Temp.	Saturation Pressure.	Specific Vol. Liquid at Saturation Pressure.	Total Heat Liquid.	Specific Heat Liquid.	Latent Heat.	Specific Vol. Saturated Vapour.	Total Heat Saturated Vapour.	ENTROPY.	
								Liquid.	Vapour.
(° C.)	cm. Mercury.	c.c. per gram.	Calories* per gram.		Calories* per gram.	c.c. per gram.	Calories* per gram.		
40	193·2		15·72	·413	85·61	165	101·33	·0536	·3271
35	165·7		13·68	·408	86·73	175	—	·0472	·3285
30	141·4	1·1386	11·66	·404	87·85	190	99·51	·0404	·3301
25	119·35	1·1287	9·69	·399	88·92	220	—	·0340	·3319
20	100·3	1·1190	7·73	·394	89·93	255	97·66	·0272	·3340
15	83·5	1·1096	5·78	·390	90·98	310	—	·0206	·3361
10	69·10	1·1005	3·84	·385	91·97	375	95·76	·0137	·3383
5	56·75	1·0916	1·95	·380	92·96	0,460	94·90	·0070	·3410
0	46·15	1·0829	0·02	·376	93·86	0,555	93·88	·0000	·3436
– 5	37·15	1·0744	– 1·82	·371	94·72	0,680	—	– ·0068	·3463
– 10	29·65	1·0662	– 3·67	·367	95·54	0,830	91·87	– ·0138	·3494
– 15	23·40	1·0581	– 5·51	·362	96·41	1,010	—	– ·0207	·3527
– 20	18·20	1·0503	– 7·33	·357	97·25	1,235	89·92	– ·0280	·3562
– 25	14·00	1·0425	– 9·12	·353	98·04	1,555	—	– ·0351	·3601
– 30	10·50	1·0350	– 10·87	·348	98·85	1,960	87·98	– ·0423	·3644

* Or Centigrade thermal units per lb.

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TABLE III

Ethyl Chloride

*Total Heat of Superheated Vapour**

Temperature (° C.).	Pressures (lb./sq. in.).												
	2.	3.	4	6.	8	10.	12.	15.	20.	25.	30.	35.	40
110	—	—	—	—	—	121·1	121·0	120·9	120·6	120·3	120·0	119·8	119·5
100	—	—	—	—	—	118·4	118·3	118·2	117·9	117·6	117·3	117·1	116·8
90	—	—	—	—	—	115·7	115·6	115·5	115·2	114·9	114·6	114·4	114·1
80	113·5	113·5	113·4	113·4	113·2	113·1	113·0	112·8	112·6	112·3	112·0	111·7	111·4
70	111·0	111·0	110·9	110·8	110·6	110·5	110·4	110·2	110·0	109·7	109·4	109·1	108·8
60	108·5	108·5	108·4	108·3	108·1	108·0	107·9	107·7	107·5	107·2	106·8	106·5	106·2
50	106·1	106·0	106·0	105·9	105·7	105·6	105·4	105·2	105·0	104·7	104·3	104·0	103·7
40	103·7	103·6	103·6	103·5	103·3	103·2	103·0	102·8	102·5	102·2	101·8	101·5	
30	101·3	101·2	101·2	101·1	100·9	100·8	100·6	100·4	100·0	99·7			
20	99·0	98·9	98·9	98·7	98·6	98·4	98·3	98·0					
10	96·7	96·6	96·6	96·4	96·3	96·1	96·0						
0	94·4	94·4	94·3	94·1	94·0								
– 10	92·2	92·2	92·0										
– 20	90·1	90·0											
– 30	88·0												

* Calories per gram or Centigrade thermal units per lb.

TABLE IV

ETHYL CHLORIDE

Specific Heat of Superheated Vapour

Temperature (° C.).	Pressure (lb. per sq in.).				
	2	10.	20.	30.	40.
110	–	·270	·271	·273	·277
100	– –	·266	·267	·269	·272
90	·256	·262	·263	·265	·268
80	·253	·257	·259	·261	·263
70	·249	·253	·255	·257	·259
60	·245	·248	·250	·253	·255
50	·242	·244	·246	·249	·251
40	·238	·241	·243	·245	·247
30	·234	·236	·238	·241	
20	·230				
10	·226				
0	·222				
– 10	·218				
– 20	·214				
– 30	·211				

TABLE V

The Properties of Saturated Vapour of Methyl Chloride (CH3Cl)

Temp., °F.	Pressure in lb. per sq. in.		Vapour.		Liquid		Heat in B.T.U. per lb.		Heat of Evaporation in B.T.U. per lb			Entropy.		
t.	Absolute p	Gauge, p'.	Vol. in cu ft. per lb. v''.	Wt. in lb. per cu. ft. y	Vol. in cu. ft. per lb. v'.	Wt. in. lb. per cu ft u	Of Liquid. q	Of Vapour $r + q$.	Total. r.	Inner r - Apu.	Outer Apu.	Of Liquid. s'.	Of Vapour. s''.	$\frac{r}{T}$
- 40	6·96	- 7·74	12·57	0·079	0·0156	63·9	- 34·0	149·3	183·3	167·1	16·17	- 0·075	0·361	0·436
- 31	8·84	- 5·86	10·07	0·099	0·0158	63·4	- 29·7	152·9	182·6	166·2	16·43	- 0·065	0·360	0·425
- 22	11·11	- 3·59	8·16	0·123	0·0159	62·9	- 25·5	156·2	181·7	165·0	16·70	- 0·055	0·359	0·414
- 13	13·82	- 0·88	6·66	0·150	0·0160	62·4	- 21·2	159·6	180·8	163·8	16·97	- 0·045	0·359	0·404
- 4	17·07	2·37	5·47	0·183	0·0162	61·8	- 17·0	162·9	179·9	162·7	17·20	- 0·036	0·358	0·394
+ 5	20·89	6·19	4·53	0·221	0·0163	61·2	- 12·7	165·8	178·5	161·1	17·44	- 0·027	0·357	0·384
14	25·38	10·68	3·78	0·265	0·0165	60·6	- 8·5	168·8	177·3	159·7	17·65	- 0·018	0·356	0·374
23	30·60	15·90	3·17	0·315	0·0166	60·1	- 4·2	171·9	176·1	158·3	17·84	- 0·009	0·355	0·364
32	36·63	21·93	2·68	0·373	0·0168	59·5	0·0	174·6	174·6	156·6	18·02	0·000	0·354	0·354
41	43·60	28·90	2·27	0·440	0·0170	58·9	4·2	177·1	172·9	154·7	18·19	0·009	0·354	0·345
50	51·60	36·90	1·94	0·516	0·0172	58·3	8·5	179·6	171·1	152·7	18·43	0·017	0·352	0·335
59	60·50	45·80	1·66	0·601	0·0173	57·7	12·7	182·0	169·3	150·8	18·47	0·025	0·351	0·326
68	71·00	56·30	1·43	0·698	0·0175	57·0	17·0	184·3	167·3	148·8	18·55	0·033	0·349	0·316
77	82·53	67·83	1·24	0·807	0·0177	56·5	21·2	186·4	165·2	146·6	18·62	0·041	0·348	0·307
86	95·53	80·83	1·07	0·930	0·0179	55·8	25·5	188·4	162·9	144·2	18·69	0·049	0·347	0·298
95	110·10	95·40	0·94	1·067	0·0181	55·2	29·7	190·2	160·5	141·8	18·70	0·057	0·346	0·289
104	126·26	111·56	0·82	1·222	0·0183	54·6	34 0	191·8	157·8	139·1	18·70	0·064	0·343	0·279

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TABLE VI

THE PROPERTIES OF SATURATED VAPOUR OF SULPHUR DIOXIDE (SO_2)

Temp., ° F.	Pressure in lb per sq in		Vapour.		Heat in B T.U per lb		Heat of Evaporation in B T U per lb			Entropy			Specific Heat
	Absolute p	Gauge p'	Vol in cu ft per lb v''.	Wt in lb per cu ft y	Of Liquid, q	Of Vapour $r + q$	Total r	Inner r Apu	Outer Apu	Of Liquid, s'.	Of Vapour, s''.	$\frac{r}{T}$	Cp
− 22	5·58	− 9·12	12·74	0·078	− 16·3	148·9	165·2	152·1	13·1	− 0·0352	0·3426	0·3778	0·339
− 13	7·28	− 7·42	9·88	0·101	− 13·7	150·3	164·0	150·7	13·3	− 0·0293	0·3381	0·3674	0·343
− 4	9·35	− 5·35	7·82	0·128	− 11·1	151·6	162·7	149·2	13·5	− 0·0234	0·3339	0·3573	0·346
+ 5	11·82	2·88	6·26	0·160	8·4	152·9	161·3	147·6	13·7	− 0·0175	0·3299	0·3474	0·350
14	14·74	− 0·04	5·08	0·197	− 5·7	154·2	159·9	146·0	13·9	− 0·0117	0·3261	0·3378	0·355
23	18·29	3·59	4·15	0·241	− 2·9	155·5	158·4	144·4	14·0	− 0·0059	0·3225	0·3284	0·359
32	22·45	7·75	3·41	0·293	0·0	156·8	156·8	142·6	14·2	0·0000	0·3190	0·3190	0·363
41	27·32	12·62	2·83	0·353	2·9	158·0	155·1	140·8	14·3	0·0059	0·3158	0·3099	0·368
50	33·01	18·31	2·37	0·422	5·9	159·1	153·2	138·8	14·4	0·0117	0·3126	0·3009	0·374
59	39·61	24·91	1·99	0·503	8·9	160·2	151·3	136·8	14·5	0·0175	0·3094	0·2919	0 37
68	47·22	32·52	1·68	0·594	11·9	161·2	149·3	134·7	14·6	0·0234	0·3065	0·2831	0·384
77	55·95	41·25	1·43	0·701	15·1	162·1	147·0	132·4	14·6	0·0293	0·3035	0·2742	0·389
86	65·94	51·24	1·22	0·822	18·2	162·9	144·7	130·0	14·7	0·0352	0·3005	0·2653	0·395
95	77·27	62·57	1·04	0·961	21·4	163·5	142·1	127·3	14·8	0·0410	0·2973	0·2563	0·401
104	90·10	75·40	0·90	1·115	24·7	163·9	139·2	124·4	14·8	0·0469	0·2940	0·2471	0·408

v = Volume of Liquid = ·01121 cu ft. per lb.

TABLE VII

Thermal Properties of CO_2

New Data Arranged as in Mollier's Paper (1) and Ewing's "Mechanical Production of Cold" (4)

Temperature.	Pressure.	Behn's Volume Liquid.	Volume of Vapour.	q	Latent Heat.	Φ	
° C.	kg./cm.^{2}	c.c./gr	c.c /gr.		r.	Liquid.	Vapour.
– 50	6·82	0·866	55·2	– 26·6	79·9	0·1064	0·2515
– 45	8·41	0·881	45·4	– 24·0	77·8	– 0·0958	0·2458
– 40	10·16	0·896	38·0	– 21·45	75·7	– 0·0850	0·2403
– 35	12·20	0·912	31·65	– 18·9	73·6	– 0·0742	0·2350
– 30	14·49	0·930	26·45	– 16·3	71·3	– 0·0635	0·2300
– 25	17·05	0·958	22·30	– 13·75	69·0	– 0·0528	0·2253
– 20	19·96	0·970	18·95	– 11·0	66·5	– 0·0422	0·2207
– 15	23·16	0·993	16·10	– 8·3	63·8	– 0·0318	0·2154
– 10	26·9	1·02	13·70	– 5·6	60·9	– 0·0211	0·2100
– 5	31·0	1·048	11·70	– 2·85	57·7	– 0·0105	0·2042
0	35·5	1·08	10·00	0·0	54·1	0·0000	0·1981
+ 5	40·5	1·119	8·55	+ 3·00	50·3	+ 0·0100	0·1919
+ 10	45·9	1·163	7·25	+ 6·05	46·2	+ 0·0223	0·1850
+ 15	51·8	1·222	6·13	+ 9·10	41·9	+ 0·0331	0·1775
+ 20	58·3	1·295	5·10	11·95	36·55	+ 0·0435	0·1682

TABLE VIII

THERMAL PROPERTIES OF CO$_2$

Temp	Pressure, Frewen Jenkin and Pye	Liquid		Latent Heat	Vapour		Vapour Density	Pressure. Kuenen and Robson and Amagat.	
° C	lb /in ²	I	ϕ	L	I	ϕ	gr /c.c.	lb /in ²	Atmospheres.
− 50	98	− 26·4	− 0·1064	79·9	53·9	0·2515	0·0181	97·0	6·60
− 45	120	− 23·8	− 0·0958	77·8	54·2	0·2458	0·0220	119·5	8·12
− 40	145	− 21·2	− 0·0850	75·7	54·5	0·2403	0·02 3	144·5	9·82
− 35	174	− 18·6	− 0·0742	73·6	55·0	0·2350	0·0316	173·5	11·8
− 30	206	− 15·95	− 0·0635	71·3	55·35	0·2300	0·0378	206·0	14·0
− 25	242½	− 13·3	− 0·0528	69·0	55·7	0·2253	0·0448	242·5	16·5
− 20	284	− 10·5	− 0·0422	66·5	56·0	0·2207	0·0528	284·0	19·3
− 15	331	− 7·7	− 0·0318	63·8	56·1	0·2154	0·0621	329·5	22·4
− 10	384	− 4·9	− 0·0211	60·9	56·0	0·2100	0·0730	382·5	26·0
− 5	443	− 2·05	− 0·0105	57·7	55·6	0·2042	0·0855	441·0	30·0
0	508	+ 0·91	0·0000	54·1	55·0	0·1981	0·100	505·0	34·35
+ 5	580	+ 4·05	+ 0·0110	50·3	54·35	0·1919	0·117	—	—
+ 10	658	+ 7·25	+ 0·0223	46·2	53·45	0·1850	0·138	653·0	44·4
+ 15	743	+ 10·4	+ 0·0331	41·9	52·3	0·1775	0·163	—	—
+ 20	835	+ 13·45	+ 0·0435	36·55	50·0	0·1682	0·196	829·0	56·4

TABLE IX

COMPARISONS BETWEEN THE SCALES OF CENTIGRADE AND FAHRENHEIT THERMOMETERS

Centigrade.	Fahrenheit.	Centigrade.	Fahrenheit.
- 40	- 40·0	- 7	+ 19·4
- 39	- 38·2	- 6	+ 21·2
38	- 36·4	- 5	+ 23·0
- 37	- 34·6	- 4	+ 24·8
36	- 32·8	- 3	+ 26·6
- 35	- 31·0	- 2	+ 28·4
- 34	- 29·2	- 1	+ 30·2
- 33	- 27·4	0	+ 32·0
- 32	- 25·6	+ 1	+ 33·8
- 31	- 23·8	+ 2	+ 35·6
- 30	- 22·0	+ 3	+ 37·4
- 29	- 20·2	+ 4	+ 39·2
- 28	18·4	+ 5	+ 41·0
- 27	- 16·6	+ 6	+ 42·8
- 26	- 14·8	+ 7	+ 44·6
- 25	- 13·0	+ 8	+ 46·4
- 24	- 11·2	+ 9	+ 48·2
- 23	- 9·3	+ 10	+ 50·0
- 22	- 7·6	+ 11	+ 51·8
- 21	- 5·8	+ 12	+ 53·6
- 20	- 4·0	+ 13	+ 55·4
- 19	- 2·2	+ 14	+ 57·2
18	- 0·4	+ 15	+ 59·0
- 17	+ 1·4	+ 16	+ 60·8
16	+ 3·2	+ 17	+ 62·6
- 15	+ 5·0	+ 18	+ 64·4
14	+ 6·8	+ 19	+ 66·2
13	+ 8·6	+ 20	+ 68·0
12	+ 10·4	+ 21	+ 69·8
11	+ 12·2	+ 22	+ 71·6
- 10	+ 14·0	+ 23	+ 73·4
- 9	+ 15·8	+ 24	+ 75·2
- 8	+ 17·6		

TABLE X

PROPERTIES OF SATURATED VAPOUR OF FREON

Reproduced by kind permission from Circular No. 12 of the American Society of Refrigerating Engineers, and with acknowledgments to Mr. Ralph M. Buffington and Mr. W. K. Gilkey, and to the Kinetic Chemicals Inc., Wilmington, Delaware.

Tem.	Pressure		Volume		Density		Heat content from − 40°			Entropy from − 40°		Tem.
°F	Abs. lb./in.²	Gage lb./in.²	Liquid ft.³/lb.	Vapor ft.³/lb.	Liquid lb./ft.³	Vapor lb./ft.³	Liquid Btu./lb.	Latent Btu./lb.	Vapor Btu./lb.	Liquid Btu./lb. °F	Vapor Btu./lb. °F	°F
t	p	p_d	v_f	v_g	$1/v_f$	$1/v_g$	h_f	h	h_g	s_f	s_f	t
−40	9·32	*10·92	0·0106	3·911	94·58	0·2557	0	73·50	73·50	0	0·17517	−40
−38	9·82	*9·91	0·0106	3·727	94·39	0·2683	0·40	73·34	73·74	0·00094	0·17490	−38
−36	10·34	*8·87	0·0106	3·553	94·20	0·2815	0·81	73·17	73·98	0·00188	0·17463	−36
−34	10·87	*7·80	0·0106	3·389	93·99	0·2951	1·21	73·01	74·22	0·00282	0·17438	−34
−32	11·43	*6·66	0·0107	3·234	93·79	0·3092	1·62	72·84	74·46	0·00376	0·17412	−32
−30	12·02	*5·45	0·0107	3·088	93·59	0·3238	2·03	72·67	74·70	0·00471	0·17387	−30
−28	12·62	*4·23	0·0107	2·950	93·39	0·3390	2·44	72·50	74·94	0·00565	0·17364	−28
−26	13·26	*2·93	0·0107	2·820	93·18	0·3546	2·85	72·33	75·18	0·00659	0·17340	−26
−24	13·90	*1·63	0·0108	2·698	92·98	0·3706	3·25	72·16	75·41	0·00753	0·17317	−24
−22	14·58	*0·24	0·0108	2·583	92·78	0·3871	3·66	71·98	75·64	0·00846	0·17296	−22
−20	15·28	0·58	0·0108	2·474	92·58	0·4042	4·07	71·80	75·87	0·00940	0·17275	−20
−18	16·01	1·31	0·0108	2·370	92·38	0·4219	4·48	71·63	76·11	0·01033	0·17253	−18
−16	16·77	2·07	0·0108	2·271	92·18	0·4403	4·89	71·45	76·34	0·01126	0·17232	−16
−14	17·55	2·85	0·0109	2·177	91·97	0·4593	5·30	71·27	76·57	0·01218	0·17212	−14
−12	18·37	3·67	0·0109	2·088	91·77	0·4789	5·72	71·09	76·81	0·01310	0·17194	−12
−10	19·20	4·50	0·0109	2·003	91·57	0·4993	6·14	70·91	77·05	0·01403	0·17175	−10
−8	20·08	5·38	0·0109	1·922	91·35	0·5203	6·57	70·72	77·29	0·01496	0·17158	−8
−6	20·98	6·28	0·0110	1·845	91·14	0·5420	6·99	70·53	77·52	0·01589	0·17140	−6
−4	21·91	7·21	0·0110	1·772	90·93	0·5644	7·41	70·34	77·75	0·01682	0·17123	−4
−2	22·87	8·17	0·0110	1·703	90·72	0·5872	7·83	70·15	77·98	0·01775	0·17107	−2
0	23·87	9·17	0·0110	1·637	90·52	0·6109	8·25	69·96	78·21	0·01869	0·17091	0
2	24·89	10·19	0·0110	1·574	90·31	0·6352	8·67	69·77	78·44	0·01961	0·17075	2
4	25·96	11·26	0·0111	1·514	90·11	0·6606	9·10	69·57	78·67	0·02052	0·17060	4
†5	26·51	11·81	0·0111	1·485	90·00	0·6735	9·32	69·47	78·79	0·02097	0·17052	†5
6	27·05	12·35	0·0111	1·457	89·88	0·6864	9·53	69·37	78·90	0·02143	0·17045	6
8	28·18	13·48	0·0111	1·403	89·68	0·7129	9·96	69·17	79·13	0·02235	0·17030	8
10	29·35	14·65	0·0112	1·351	89·45	0·7402	10·39	68·97	79·36	0·02328	0·17015	10
12	30·56	15·86	0·0112	1·301	89·24	0·7687	10·82	68·77	79·59	0·02419	0·17001	12
14	31·80	17·10	0·0112	1·253	89·03	0·7981	11·26	68·56	79·82	0·02510	0·16987	14
16	33·08	18·38	0·0112	1·207	88·81	0·8288	11·70	68·35	80·05	0·02601	0·16974	16
18	34·40	19·70	0·0113	1·163	88·58	0·8598	12·12	68·15	80·27	0·02692	0·16961	18
20	35·75	21·05	0·0113	1·121	88·37	0·8921	12·55	67·94	80·49	0·02783	0·16949	20
22	37·15	22·45	0·0113	1·081	88·13	0·9251	13·00	67·72	80·72	0·02873	0·16938	22
24	38·58	23·88	0·0113	1·043	87·91	0·9588	13·44	67·51	80·95	0·02963	0·16926	24
26	40·07	25·37	0·0114	1·007	87·68	0·9930	13·88	67·29	81·17	0·03053	0·16913	26
28	41·59	26·89	0·0114	0·973	87·47	1·028	14·32	67·07	81·39	0·03143	0·16900	28
30	43·16	28·46	0·0115	0·939	87·24	1·065	14·76	66·85	81·61	0·03233	0·16887	30
32	44·77	30·07	0·0115	0·908	87·02	1·102	15·21	66·62	81·83	0·03323	0·16876	32
34	46·42	31·72	0·0115	0·877	86·78	1·140	15·65	66·40	82·05	0·03413	0·16865	34
36	48·13	33·43	0·0116	0·848	86·55	1·180	16·10	66·17	82·27	0·03502	0·16854	36
38	49·88	35·18	0·0116	0·819	86·33	1·221	16·55	65·94	82·49	0·03591	0·16843	38
40	51·68	36·98	0·0116	0·792	86·10	1·263	17·00	65·71	82·71	0·03680	0·16833	40
42	53·51	38·81	0·0116	0·767	85·88	1·304	17·46	65·47	82·93	0·03770	0·16823	42
44	55·40	40·70	0·0117	0·742	85·66	1·349	17·91	65·24	83·15	0·03859	0·16813	44

Inches of mercury below one atmosphere. † Standard ton temperatures.

PROPERTIES OF SATURATED VAPOUR—*Continued*

Tem.	Pressure		Volume		Density		Heat content from − 40°			Entropy from − 40°		Tem.
°F t	Abs. lb./in.^{2} p	Gage lb./in.^{2} p_d	Liquid ft.^{3}/lb. v_f	Vapor ft.^{3}/lb. v_g	Liquid lb./ft.^{3} $1/v_f$	Vapor lb./ft.^{3} $1/v_g$	Liquid Btu./lb. h_f	Latent Btu./lb. h	Vapor Btu./lb. h_g	Liquid Btu./lb. °F s_f	Vapor Btu./lb. °F s_g	°F t
46	57·35	42·65	0·0117	0·718	85·43	1·393	18·36	65·00	83·36	0·03948	0·16803	46
48	59·35	44·65	0·0117	0·695	85·19	1·438	18·82	64·74	83·57	0·04037	0·16794	48
50	61·39	46·69	0·0118	0·673	84·94	1·485	19·27	64·51	83·78	0·04126	0·16785	50
52	63·49	48·79	0·0118	0·652	84·71	1·534	19·72	64·27	83·99	0·04215	0·16776	52
54	65·63	50·93	0·0118	0·632	84·50	1·583	20·18	64·02	84·20	0·04304	0·16767	54
56	67·84	53·14	0·0119	0·612	84·28	1·633	20·64	63·77	84·41	0·04392	0·16758	56
58	70·10	55·40	0·0119	0·593	84·04	1·686	21·11	63·51	84·62	0·04480	0·16749	58
60	72·41	57·71	0·0119	0·575	83·78	1·740	21·57	63·25	84·82	0·04568	0·16741	60
62	74·77	60·07	0·0120	0·557	83·57	1·795	22·03	62·99	85·02	0·04657	0·16733	62
64	77·20	62·50	0·0120	0·540	83·34	1·851	22·49	62·73	85·22	0·04745	0·16725	64
66	79·67	64·97	0·0120	0·524	83·10	1·909	22·95	62·47	85·42	0·04833	0·16717	66
68	82·24	67·54	0·0121	0·508	82·86	1·968	23·42	62·20	85·62	0·04921	0·16709	68
70	84·82	70·12	0·0121	0·493	82·60	2·028	23·90	61·92	85·82	0·05009	0·16701	70
72	87·50	72·80	0·0121	0·479	82·37	2·090	24·37	61·65	86·02	0·05097	0·16693	72
74	90·20	75·50	0·0122	0·464	82·12	2·153	24·84	61·38	86·22	0·05185	0·16685	74
76	93·00	78·30	0·0122	0·451	81·87	2·218	25·32	61·10	86·42	0·05272	0·16677	7g
78	95·85	81·15	0·0123	0·438	81·62	2·284	25·80	60·81	86·61	0·05359	0·16669	78
80	98·76	84·06	0·0123	0·425	81·39	2·353	26·28	60·52	86·80	0·05446	0·16662	80
82	101·7	87·00	0·0123	0·413	81·12	2·423	26·76	60·23	86·99	0·05534	0·16655	82
84	104·8	90·1	0·0124	0·401	80·87	2·495	27·24	59·94	87·18	0·05621	0·16648	84
†86	107·9	93·2	0·0124	0·389	80·63	2·569	27·72	59·65	87·37	0·05708	0·16640	†86
88	111·1	96·4	0·0124	0·378	80·37	2·645	28·21	59·35	87·56	0·05795	0·16632	88
90	114·3	99·6	0·0125	0·368	80·11	2·721	28·70	59·04	87·74	0·05882	0·16624	90
92	117·7	103·0	0·0125	0·357	79·86	2·799	29·19	58·73	87·92	0·05969	0·16616	92
94	121·0	106·3	0·0126	0·347	79·60	2·880	29·68	58·42	88·10	0·06056	0·16608	94
96	124·5	109·8	0·0126	0·338	79·32	2·963	30·18	58·10	88·28	0·06143	0·16600	96
98	128·0	113·3	0·0126	0·328	79·06	3·048	30·67	57·78	88·45	0·06230	0·16592	98
100	131·6	116·9	0·0127	0·319	78·80	3·135	31·16	57·46	88·62	0·06316	0·16584	100
102	135·3	120·6	0·0127	0·310	78·54	3·224	31·65	57·14	88·79	0·06403	0·16576	102
104	139·0	124·3	0·0128	0·302	78·27	3·316	32·15	56·80	88·95	0·06490	0·16568	104
106	142·8	128·1	0·0128	0·293	78·00	3·411	32·65	56·46	89·11	0·06577	0·16560	106
108	146·8	132·1	0·0129	0·285	77·73	3·509	33·15	56·12	89·27	0·06663	0·16551	108
110	150·7	136·0	0·0129	0·277	77·46	3·610	33·65	55·78	89·43	0·06749	0·16542	110
112	154·8	140·1	0·0130	0·269	77·18	3·714	34·15	55·43	89·58	0·06836	0·16533	112
114	158·9	144·2	0·0130	0·262	76·89	3·823	34·65	55·08	89·73	0·06922	0·16524	114
116	163·1	148·4	0·0131	0·254	76·60	3·934	35·15	54·72	89·87	0·07008	0·16515	116
118	167·4	152·7	0·0131	0·247	76·32	4·049	35·65	54·36	90·01	0·07094	0.16505	118
120	171·8	157·1	0·0132	0·240	76·02	4·167	36·16	53·99	90·15	0·07180	0·16495	120
122	176·2	161·5	0·0132	0·233	75·72	4·288	36·66	53·62	90·28	0·07266	0·16484	122
124	180·8	166·1	0·0133	0·227	75·40	4·413	37·16	53·24	90·40	0·07352	0·16473	124
126	185·4	170·7	0·0133	0·220	75·10	4·541	37·67	52·85	90·52	0·07437	0·16462	126
123	190·1	175·4	0·0134	0·214	74·78	4·673	38·18	52·46	90·64	0·07522	0·16450	128
130	194·9	180·2	0·0134	0·208	74·46	4·808	38·69	52·07	90·76	0·07607	0·16438	130
132	199·8	185·1	0·0135	0·202	74·13	4·948	39·19	51·67	90·86	0·07691	0·16425	132
134	204·8	190·1	0·0135	0·196	73·81	5·094	39·70	51·26	90·96	0·07775	0·16411	134
136	209·9	195·2	0·0136	0·191	73·46	5·247	40·21	50·85	91·06	0·07858	0·16396	136
138	215·0	200·3	0·0137	0·185	73·10	5·405	40·72	50·43	91·15	0·07941	0·16380	138
140	220·2	205·5	0·0138	0·180	72·73	5·571	41·24	50·00	91·24	0·08024	0·16363	140

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